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FINAL
TREATABILITY STUDY IN SUPPORT OF REMEDIATION BY NATURAL ATTENUATION SITE FT-1

at

FAIRCHILD AIR FORCE BASE
SPOKANE, WASHINGTON

October 1997

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

AND

92ND CES/CEVR
FAIRCHILD AIR FORCE BASE
SPOKANE, WASHINGTON

Prepared by:

Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290

EXECUTIVE SUMMARY

This report presents the results of a treatability study performed by Parsons Engineering Science, Inc. (Parsons ES) at the FT-1 Site, Fairchild Air Force Base, Washington to evaluate remediation by natural attenuation (RNA) of dissolved fuel-hydrocarbons and chlorinated solvents in the shallow groundwater. RNA will supplement the engineered remedial actions prescribed in the Record of Decision (ROD). Residual nonaqueous-phase liquid (NAPL) present within the vadose zone and phreatic soils serves as a continuing source for the dissolved groundwater contamination. There is no evidence of mobile NAPL at this site. This study focused on the fate and transport of dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) in the shallow groundwater system at the site. Dissolved chlorinated aliphatic hydrocarbons (CAHs) also are present in the shallow groundwater; therefore, the potential for RNA of these compounds was investigated as well. Site history and the results of soil and groundwater investigations conducted previously are also summarized in this report.

Comparison of BTEX, CAH, electron acceptor, and biodegradation byproduct isopleth maps for Site FT-1 provides strong qualitative evidence of biodegradation of BTEX and CAHs. Geochemical data strongly suggest that biodegradation of fuel hydrocarbons is occurring at the site via aerobic respiration and the anaerobic processes of denitrification, iron reduction, sulfate reduction, and methanogenesis. Patterns observed in the distribution of hydrocarbons, electron acceptors, and biodegradation byproducts further indicate that biodegradation is reducing dissolved BTEX concentrations in site groundwater. In addition, the ratio of trichloroethene (TCE) and *cis*-1,2-dichloroethene (1,2-DCE) to the daughter product vinyl chloride (VC) suggests that chlorinated solvents in the groundwater are being degraded through reductive dehalogenation.

An important component of this study was an assessment of the potential for contamination in groundwater to migrate from the source areas to potential receptors. The Bioplume II numerical model was used to evaluate the fate and transport of dissolved BTEX in the shallow groundwater under the influence of advection, dispersion, sorption, and biodegradation. Input parameters for the Bioplume II model were obtained from previous site characterization data, supplemented with data collected by Parsons ES. Model parameters that were not measured at the site were estimated using reasonable literature values.

The results of this demonstration suggest that RNA of BTEX and CAHs is occurring at FT-1; furthermore, the estimated rates of biodegradation, when coupled with the effects of sorption, dispersion, and dilution, should be sufficient to reduce and maintain dissolved BTEX and CAHs at levels below current regulatory guidelines long before potential downgradient receptors could be adversely affected. Nevertheless, dissolved concentrations of BTEX and chlorinated solvents are predicted to remain in shallow site groundwater for at least 34 years without engineered source reduction. Given the possible stabilization and retreat of the dissolved BTEX plume, RNA with LTM is a viable remedial option for BTEX-impacted groundwater at the site. However, due to

the ROD cleanup goal for benzene [5 micrograms per liter (µg/L)], RNA with LTM should be used to complement the ROD-mandated bioventing and air sparging systems. When bioventing and air sparging are incorporated into the site groundwater model, the model predicts it will take approximately 19 years to reduce dissolved benzene concentrations to below 5 µg/L.

To verify the results of the analytical modeling effort, and to ensure that RNA is occurring at rates sufficient to protect potential downgradient receptors, groundwater from 10 LTM wells, including 7 plume-extent wells and 3 downgradient base-boundary wells, should be sampled and analyzed for BTEX compounds by US Environmental Protection Agency (USEPA) Method SW8020 and chlorinated solvents by USEPA method SW8010 (or equivalent). These wells should be sampled annually for 10 years. At that time, sampling could cease, decrease in frequency, or continue annually as dictated by the analytical results. If dissolved BTEX or CAH concentrations in groundwater collected from the downgradient base-boundary wells exceed ROD or regulatory criteria, additional evaluation or corrective action may be necessary at this site.

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SECTION 1

INTRODUCTION

This report was prepared by Parsons Engineering Science, Inc. [(Parsons ES), formerly Engineering-Science Inc. (ES)] and presents the results of a Treatability Study (TS) conducted to evaluate remediation by natural attenuation (RNA), or intrinsic remediation, of fuel-hydrocarbon- and chlorinated-solvent-contaminated groundwater at Fire Training Area 1 (FT-1) at Fairchild Air Force Base (AFB), Spokane, Washington. In June 1993, a record of decision (ROD) was issued for several sites at Fairchild AFB, including FT-1 [Halliburton NUS (HNUS), 1993a]. The ROD identifies benzene as the primary contaminant of concern (COC) for FT-1 and specifies the use of air sparging in the remediation system. The main emphasis of the work described herein was to evaluate the effectiveness of natural attenuation mechanisms, in concert with proposed air sparging system configurations, in reducing dissolved benzene concentrations in groundwater to levels that comply with the mandates of the ROD. Although other fuel hydrocarbon and chlorinated solvent compounds were not identified in the ROD as COCs for FT-1, the potential for natural attenuation mechanisms to effectively reduce low, dissolved concentrations of these compounds in site groundwater also was qualitatively considered.

As used in this report, RNA refers to a management strategy that relies on natural attenuation mechanisms to remediate contaminants dissolved in groundwater and to control receptor exposure risks associated with contaminants in the subsurface. The United States Environmental Protection Agency (USEPA) Office of Research and Development (ORD) and Office of Solid Waste and Emergency Response (OSWER) define natural attenuation as:

> *The biodegradation, dispersion, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.*

As suggested by this definition, mechanisms for natural attenuation of benzene and other organic compounds include advection, dispersion, dilution from recharge, sorption, volatilization, and biodegradation. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. Contaminant destruction occurs through biodegradation when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without artificial intervention (e.g., the addition of nutrients). Patterns

and rates of natural attenuation can vary markedly from site to site, and within a single contaminant plume at a given site, depending on governing physical and chemical processes.

1.1 SCOPE AND OBJECTIVES

Parsons ES, in conjunction with researchers from the USEPA National Risk Management Research Laboratory (NRMRL) Subsurface Protection and Remediation Division, was retained by the United States Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division to conduct site characterization and groundwater modeling to evaluate the scientific defensibility of RNA with long-term monitoring (LTM) as a component of remediation for contaminated groundwater at FT-1.

There were two primary objectives of this project:

- Determine whether natural attenuation processes for fuel hydrocarbons and chlorinated solvents are occurring in groundwater at the site, and if so,
- Investigate the use of these processes as a component of the ROD-specified remediation system to minimize the expansion of the benzene plume and to ensure compliance with groundwater protection standards set forth in the ROD.

These objectives were accomplished by:

- Reviewing previously reported hydrogeologic, soil and groundwater quality data for the site;
- Conducting supplemental site characterization activities to determine the nature and extent of soil and groundwater contamination;
- Collecting geochemical data in support of RNA;
- Developing a conceptual hydrogeologic model of the shallow saturated zone, including the current distribution of contaminants;
- Evaluating site-specific data to determine whether natural processes of contaminant attenuation and destruction are occurring in groundwater for dissolved concentrations of fuel hydrocarbon and chlorinated solvent compounds at the site;
- Using the Bioplume II numerical model to simulate the fate and transport of benzene in groundwater under the influence of biodegradation, advection, dispersion, and adsorption;
- Evaluating a range of model input parameters to determine the sensitivity of the model to those parameters and to consider several contaminant fate and transport scenarios;

- Determining if natural processes in concert with air sparging are sufficient to reduce dissolved benzene concentrations and limit benzene plume expansion in order to attain compliance with the ROD;

- Using the results of modeling to recommend the most appropriate air sparging configuration; and

- Providing a LTM plan that includes LTM and point-of-compliance (POC) well locations and a sampling and analysis plan.

The field work conducted under this program was oriented toward collecting supplementary hydrogeological and chemical data necessary to document and model natural attenuation mechanisms currently operating at the site. During November 1995, site characterization activities included use of the Geoprobe® direct-push technology for soil sample collection and temporary monitoring point installation; aquifer testing; and sampling and analysis of groundwater from temporary groundwater monitoring points and previously installed monitoring wells. In May 1996, a temporary Geoprobe® monitoring point was installed within the FT-1 burn pit to further characterize site groundwater. Much of the hydrogeological and groundwater chemical data necessary to evaluate RNA were available from previous investigations conducted at this site, at other sites with similar characteristics, or in technical literature.

Site-specific data were used to develop a fate and transport model for the site, using the groundwater flow and solute transport model Bioplume II, to evaluate processes of natural attenuation. The Bioplume II model was used to simulate the movement of dissolved benzene in the shallow saturated zone under the influence of biodegradation, advection, dispersion, and sorption. Results of the model were used to assess the effectiveness of natural attenuation mechanisms in concert with proposed air sparging configurations at achieving the conditions of the ROD.

Site-specific data also were used to qualitatively evaluate the potential fate and transport of trichloroethene (TCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), and vinyl chloride in the presence of fuel hydrocarbons. Potential biological degradation of these chlorinated solvents via reductive dehalogenation and cometabolic processes was addressed qualitatively.

This report contains eight sections, including this introduction, and four appendices. Section 2 summarizes site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil and groundwater contamination and the geochemistry of soil and groundwater at the site. Section 5 describes the Bioplume II model and design of the conceptual model for the site, lists model assumptions and input parameters, and describes sensitivity analysis, model output, and the results of the Bioplume II modeling. Section 5 also includes a qualitative analysis of the fate and transport of chlorinated solvents. Section 6 describes how natural attenuation acts in concert with the ROD-specified air sparging system to achieve groundwater remediation throughout the plume, and present a LTM plan for the site. Section 7 presents the conclusions of this work and provides

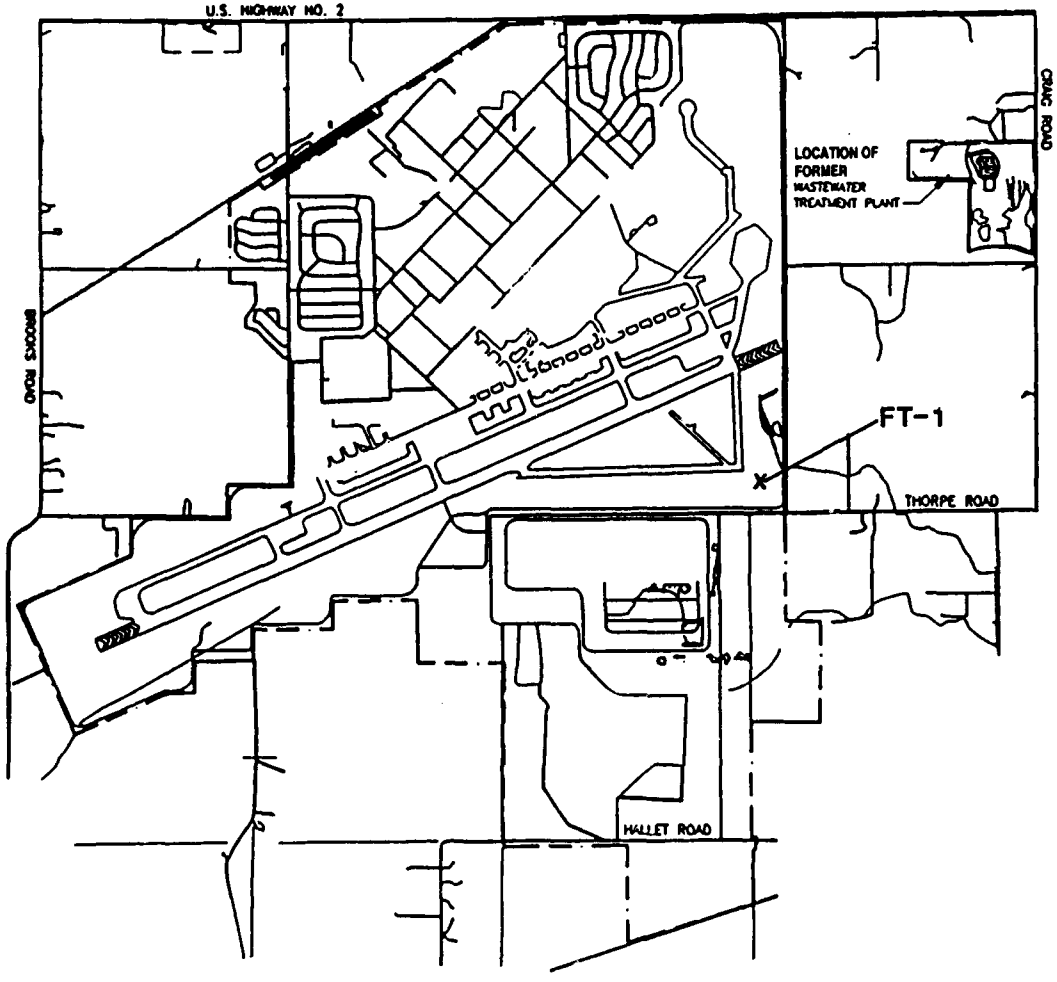
recommendations for further work at the site. Section 8 lists the references used to develop this document. Appendix A contains Geoprobe® borehole logs, monitoring point installation records, and slug test results. Appendix B presents soil and groundwater analytical results. Appendix C contains calculations and model input parameters. Appendix D contains Bioplume II model input and output in American Standard Code for Information Interchange (ASCII) format on a diskette.

1.2 FACILITY BACKGROUND

Fairchild AFB occupies an area of approximately 4,300 acres 12 miles west of Spokane, Washington. The Base is divided roughly in half by the main northeast/southwest runway (Figure 1.1). Aircraft operational facilities, approximately 1,600 Base housing units, an elementary school, a hospital, and support facilities for the tenants housed on-Base lie north of the runway. The air traffic control tower, weapons storage area, and survival training school lie to the south of the runway [Halliburton NUS (HNUS), 1993b].

The Base was established in 1942 as an Army repair depot and was transferred to the Strategic Air Command (SAC) in 1947. In 1992, Base control was transferred to the Air Combat Command (ACC). Currently, the Base is operated by the Air Mobility Command (AMC) and serves as host to the 92nd Air Refueling Wing. The Base also is the current home of the 141st Air Refueling Wing of the Washington Air National Guard (WANG), aircraft operational facilities, a weapons storage area, and a survival training school. Base operations employ approximately 5,000 civilian and military personnel (ES, 1994).

Site FT-1 is a former fire training area located near the eastern property boundary of the Base between Taxiway 10 and Perimeter Road (Figure 1.2). Surface features at the site include a concrete fire training building (Building 1570), a bioventing equipment shed, and a concrete slab. A large gravel pad surrounds all of these surface features. An unlined fire pit is located immediately south of Building 1570 (Figure 1.2). The pit was constructed in 1970 using bermed gravel, and a mock aircraft was formerly located in the center of the pit. Prior to 1970, fire training exercises were performed in an unlined pit formerly located immediately north of the current lined fire training pit, near Building 1570. A 4,000-gallon underground storage tank (UST) formerly located east of Building 1570 was used to store fuels used for fire training exercises. Pressure tests performed on this tank in 1989 did not indicated the presence of poten'ial leaks. Additionally, an oil/water separator is located within the gravel pad approximately 150 feet east of the current training pit (Figure 1.2). It was used to separate unburned fuels from water that remained in the training pit after training exercises were conducted. A poorly defined manmade ditch receives effluent from the oil/water separator and discharges in a wide, flat, marshy area where effluent infiltrates the ground surface (HNUS, 1993b).

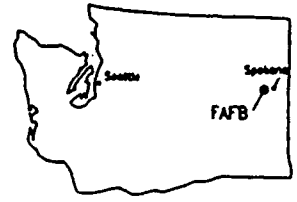


LEGEND

- SURFACE WATER FEATURE
- BASE BOUNDRY

N

0 1000 2000 3000 4000
SCALE IN FEET



Key Plan

Source: ICF Technology Inc., 1995.

FIGURE 1.1

SITE LOCATION

Site FT-1
Remediation by Natural Attenuation
Fairchild AFB, Washington

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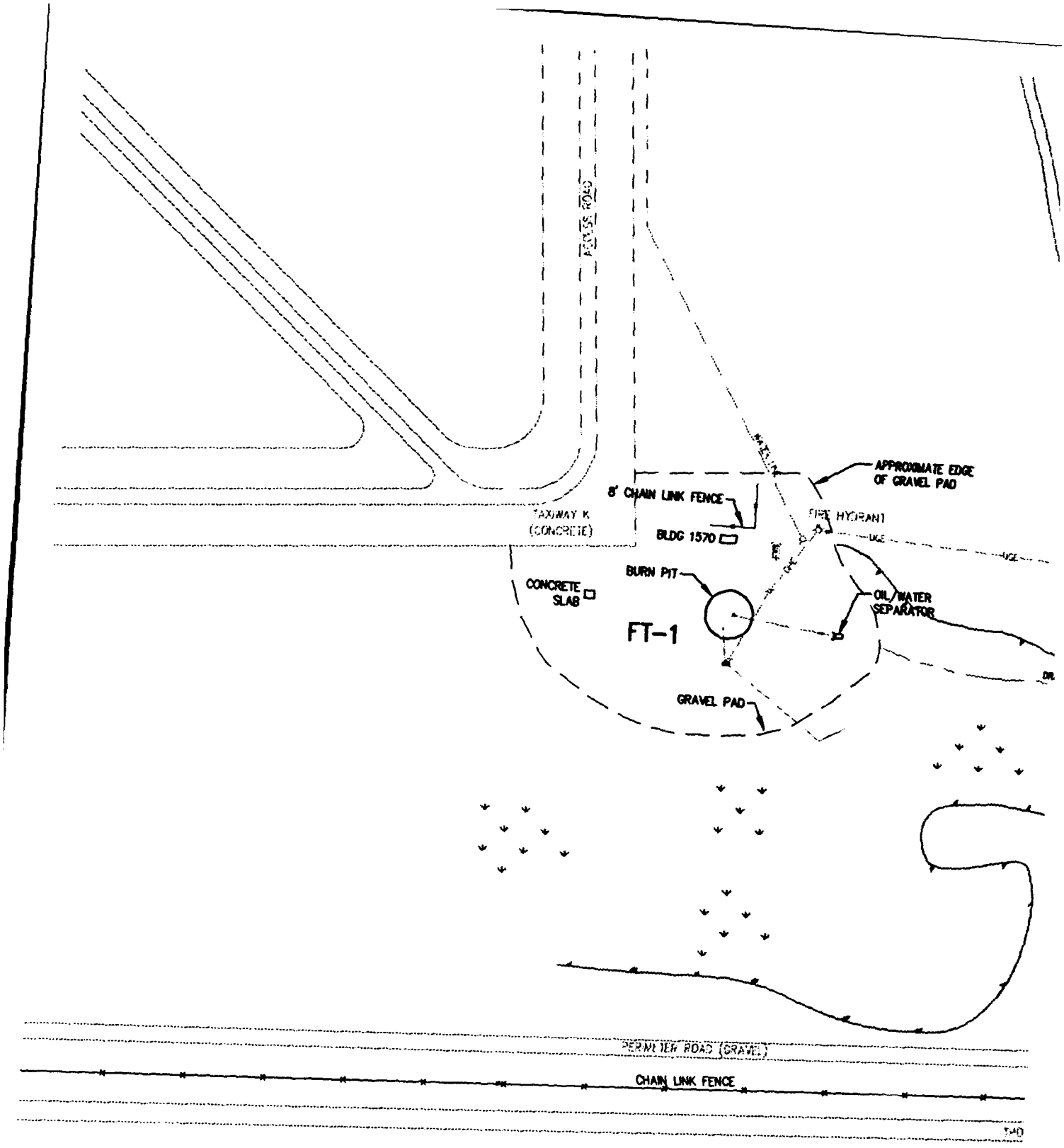
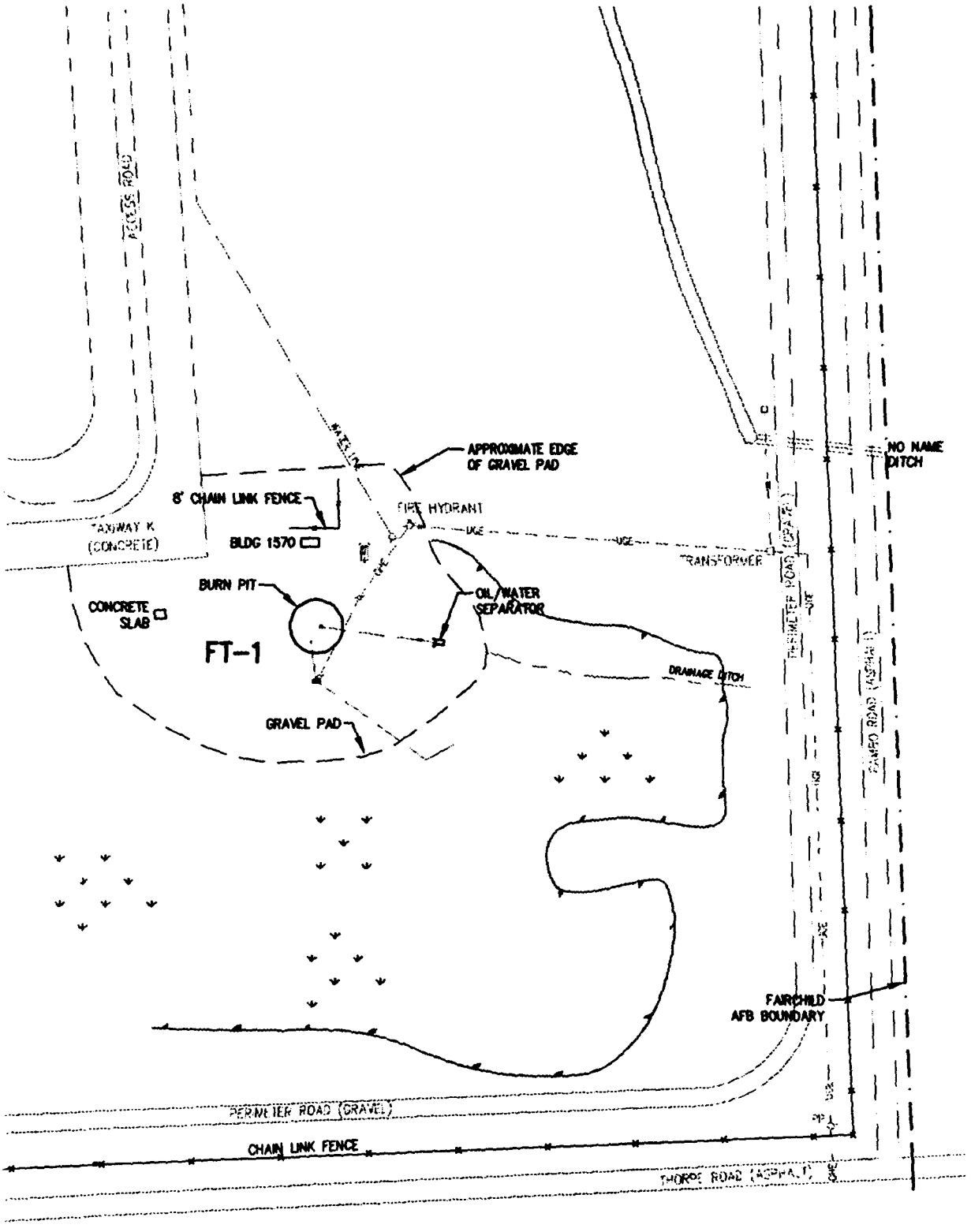
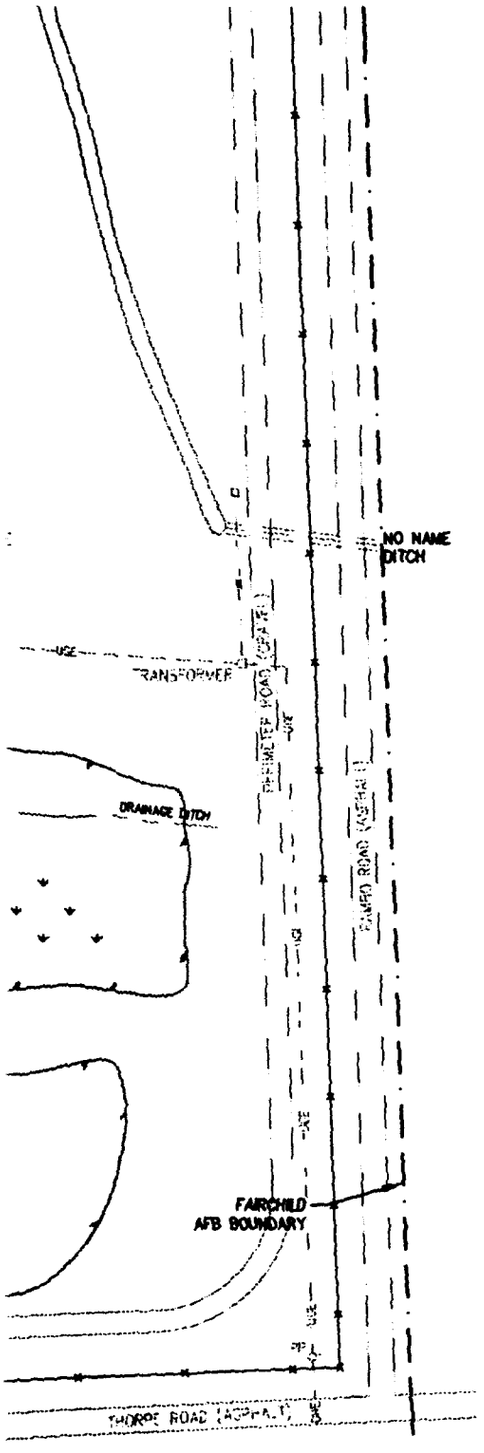
Denver, Colorado


ACCESS ROAD
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
TAXIWAY K (CONCRETE)
BLDG 1570
FIRE HYDRANT
BURN PIT
CONCRETE SLAB
OIL/WATER SEPARATOR
FT-1
GRAVEL PAD
PERIMETER ROAD (GRAVEL)
CHAIN LINK FENCE


PERIMETER ROAD
APPROXIMATE EDGE OF GRAVEL PAD
NO NAME DITCH
8' CHAIN LINK FENCE
FIRE HYDRANT
TAXIWAY K (CONCRETE)
BLDG 1570
TRANSFORMER
BURN PIT
OIL/WATER SEPARATOR
CONCRETE SLAB
FT-1
DRAINAGE DITCH
PERIMETER ROAD (GRAVEL)
GRAVEL PAD
PERIMETER ROAD (ASPHALT)
RAMPO ROAD (ASPHALT)
FAIRCHILD AFB BOUNDARY
CHAIN LINK FENCE
THORPE ROAD (ASPHALT)



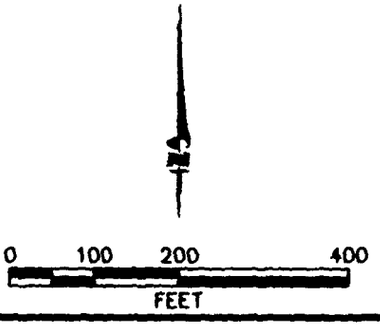


FIGURE 1.2

SITE FT-1
LAYOUT

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Fire training exercises were conducted regularly at FT-1 from 1970 until operations ceased in August 1991. Recent exercises consisted of filling the training pit with 2 to 3 inches of water and spraying approximately 300 gallons of fuel over the top of the water. The fuel was then ignited, and aqueous film-forming foam (AFFF) was applied to extinguish the fire. In recent exercises, only uncontaminated fuels were used. However, during historical exercises, waste fuels and other types of hazardous waste substances were used. The nature of these other wastes is unknown (HNUS, 1993b).

Investigations were initiated at FT-1 as a result of Installation Restoration Program (IRP) Phase 1 Record Search conclusions (JRB Associates, 1985). The presence of groundwater contamination was confirmed in the IRP Phase II Confirmations/ Quantification study performed by Battelle Denver Operations (1989). Since that time, a remedial investigation (RI) has been completed by HNUS (1993b), an analytical informal technical information report (ITIR) for long-term groundwater monitoring has been submitted by EA Engineering, Science, and Technology and Montgomery Watson Americas, Inc. (ES&T and MWA, 1995), and a remediation pilot study is currently being performed (Parsons ES, 1994).

To date, soil contamination has been detected near the current fire training pit and near the outfall of the oil/water separator. Dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) contamination has been detected in groundwater samples collected near the current fire training pit. In addition, dissolved chlorinated aliphatic hydrocarbon (CAH) contamination has been detected at low concentrations, typically less than 5 micrograms per liter (µg/L), in samples collected from groundwater underlying the site and as far as 5,500 feet downgradient from the site. Dissolved BTEX concentrations, have been measured at concentrations significantly higher than dissolved CAH concentrations, with total dissolved BTEX concentrations as high as 1,320 µg/L measured in groundwater samples collected during previous investigations. The presence of mobile light nonaqueous-phase liquid (LNAPL) (i.e., free product) or dense nonaqueous-phase liquid (DNAPL) was not detected during previous site investigations.

SECTION 2

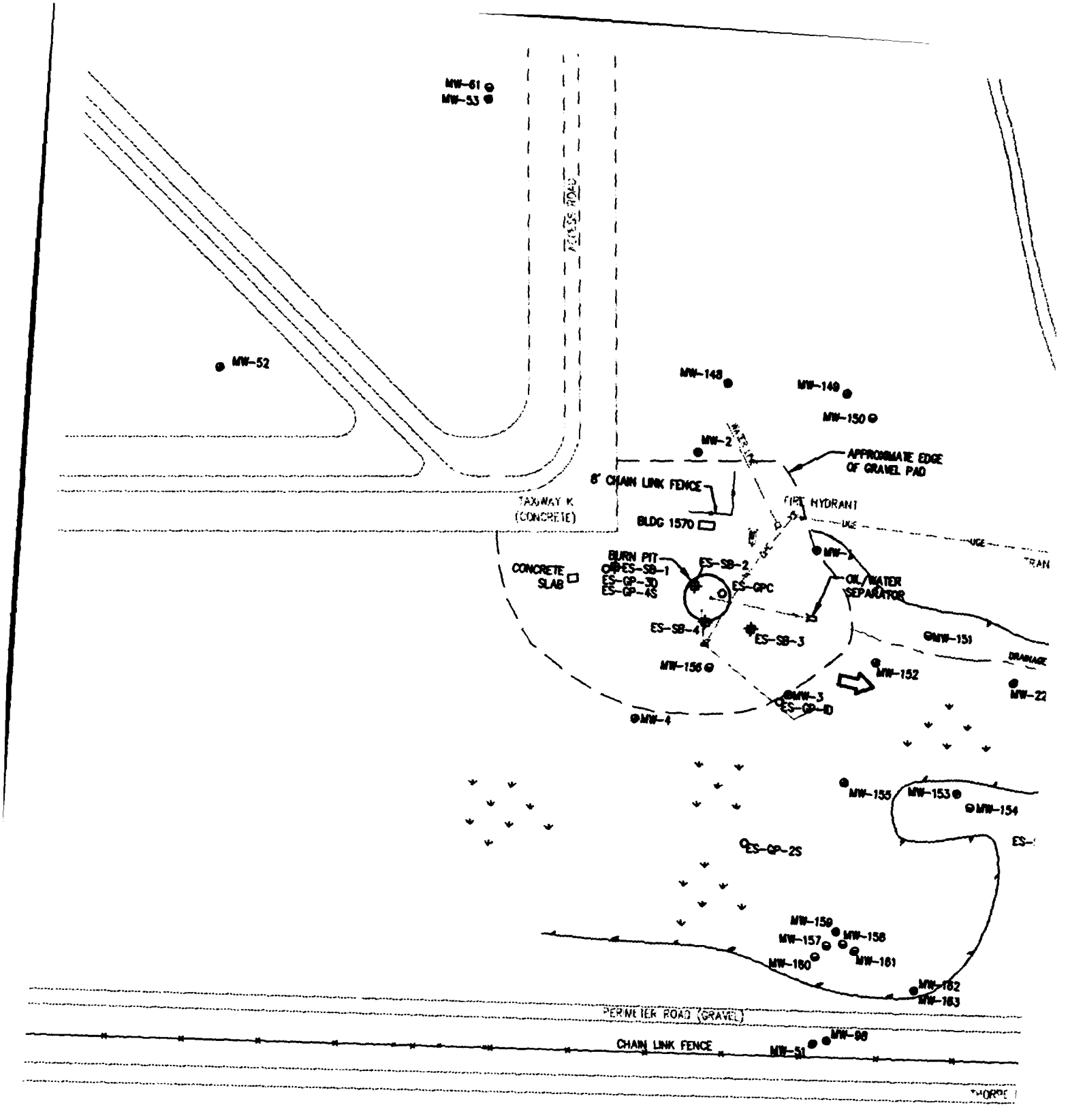
SITE CHARACTERIZATION ACTIVITIES

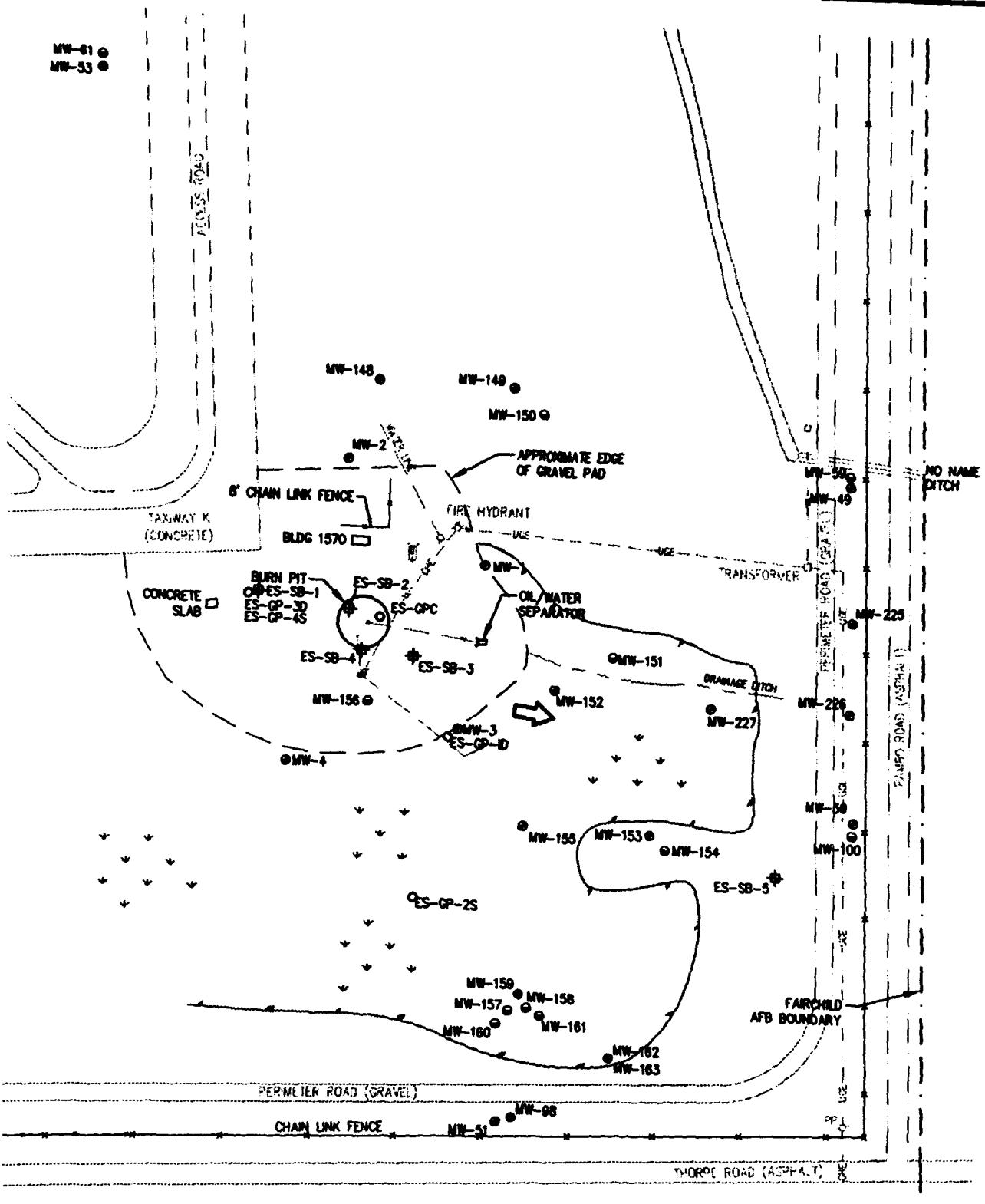
This section presents the methods used by Parsons ES personnel to collect site-specific data at FT-1, Fairchild AFB, Washington. To meet the requirements of the RNA demonstration, additional data were required to evaluate near-surface geology, aquifer properties, and the extent of soil and groundwater contamination. Site characterization activities involved using the Geoprobe® direct-push system for soil sampling and temporary groundwater monitoring point placement. Groundwater sampling was accomplished during this investigation using both temporary monitoring points and previously installed monitoring wells. Hydraulic conductivity (slug) tests were conducted at several of the site monitoring wells. Previously collected data and data collected under this program were integrated to develop the conceptual hydrogeologic site model and to aid interpretation of the physical setting (Section 3) and contaminant distribution (Section 4).

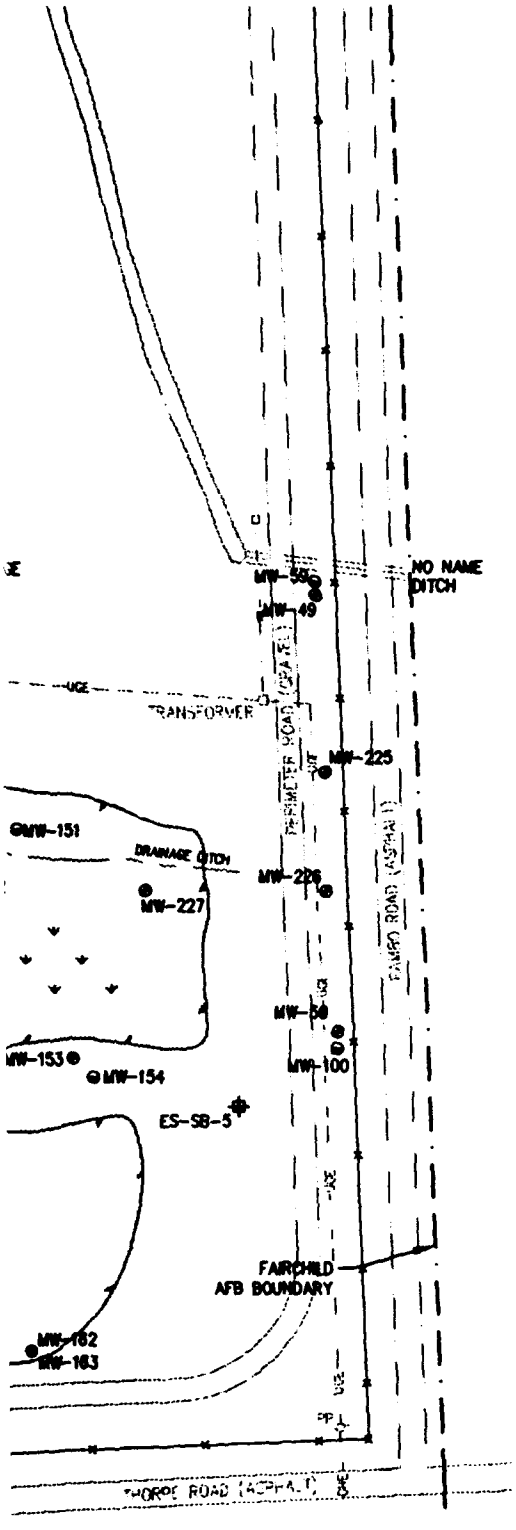
The following sections describe the procedures that were followed when collecting site-specific data. Additional details regarding investigative activities are presented in the TS work plan (Parsons ES, 1995).

2.1 SOIL SAMPLING AND MONITORING POINT INSTALLATION

The majority of Geoprobe®-related field work occurred between October 31 and November 7, 1995, and consisted of soil sampling and temporary groundwater monitoring point installation. Four monitoring points were installed at three locations during this time to assist in the characterization of the contaminant distribution and the shallow groundwater flow system at FT-1. These points are identified as ES-GP-1D, ES-GP-2S, ES-GP-3D, and ES-GP-4S. In May 1996, one additional temporary monitoring point (ES-GPC) was installed in the burn pit using a Geoprobe®. The temporary monitoring locations are shown on Figure 2.1; Table 2.1 presents completion details. Nested points were installed in pairs adjacent to each other or existing wells. Points screened across the water table (i.e., shallow points) were designated by the suffix "S"; and points screened at the base of the alluvium (i.e., deep points) were designated by the suffix "D". These monitoring point locations were selected to provide the hydrogeologic data necessary for implementation of the Bioplume II model and to evaluate the occurrence and rate of natural attenuation. These activities were performed according to the procedures described in the work plan (Parsons ES, 1995) and in the following sections.


MW-61
MW-53
ACCESS ROAD
MW-52
MW-148
MW-149
MW-150
MW-2
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
TAXIWAY K (CONCRETE)
BLDG 1570
FIRE HYDRANT
BURN PIT
ES-SB-1
ES-GP-3D
ES-GP-4S
ES-SB-2
ES-GPC
CONCRETE SLAB
OIL/WATER SEPARATOR
MW-1
ES-SB-4
ES-SB-3
GMW-151
MW-156
MW-152
DRAINAGE
MW-22
GMW-3
ES-GP-1D
MW-4
MW-155
MW-153
MW-154
ES-GP-2S
MW-159
MW-158
MW-157
MW-161
MW-160
MW-162
MW-163
PERIMETER ROAD (GRAVEL)
CHAIN LINK FENCE
MW-51
MW-99


MW-61
MW-53
TAXIWAY K (CONCRETE)
MW-148
MW-149
MW-150
MW-2
APPROXIMATE EDGE OF GRAVEL PAD
6' CHAIN LINK FENCE
FIRE HYDRANT
BLDG 1570
UGE
TRANSFORMER
MW-1
OIL/WATER SEPARATOR
BURN PIT
ES-SB-1
ES-GP-3D
ES-GP-4S
ES-SB-2
ES-GPC
CONCRETE SLAB
ES-SB-4
ES-SB-3
GMW-151
DRAINAGE DITCH
MW-156
MW-152
MW-227
GMW-3
ES-GP-1D
MW-4
MW-155
MW-153
MW-154
ES-SB-5
ES-GP-2S
MW-159
MW-158
MW-157
MW-161
MW-160
MW-162
MW-163
FAIRCHILD AFB BOUNDARY
PERIMETER ROAD (GRAVEL)
CHAIN LINK FENCE
MW-51
MW-98
THORPE ROAD (ASPHALT)
MW-50
MW-49
NO NAME DITCH
PERIMETER ROAD (ASPHALT)
MW-225
MW-226
MW-99
MW-100
RAMPO ROAD (ASPHALT)



LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- TEMPORARY MONITORING POINT AND SOIL SAMPLING LOCATION
- SOIL SAMPLING LOCATION
- APPROXIMATE GROUNDWATER FLOW DIRECTION

0 100 200 400

FEET

FIGURE 2.1

SITE FT-1
SAMPLING LOCATIONS

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

TABLE 2.1
SUMMARY OF WELL INSTALLATION DETAILS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Well Identification	Depth to Bottom of Well (feet bgs)	Screened Interval (feet bgs)	Elevation of Reference Point for Measurements (feet msl)
MW-1	13.5	4.5-10	2404.10
MW-2	13.1	6.3-11.8	2405.79
MW-3	11.0	3.5-9	2403.29
MW-4	15.0	7.4-12.9	2404.64
MW-49	11.5	8-13	2401.18
MW-50	17.5	6-16	2400.11
MW-51	10.0	5-10	2400.77
MW-52	15.6	5.6-15.6	2409.39
MW-53	21.6	11.5-21.5	2409.75
MW-59	73.5	59.5-70	2401.28
MW-61	72.0	59.5-70	2408.60
MW-98	203.5	193.1-203.5	2400.35
MW-100	44.0	43.1-53.4	2400.60
MW-148	13.2	5-10	2407.09
MW-149	16.4	9-14	2407.06
MW-150	42.3	32-42	2406.88
MW-151	32.0	20-30	2400.53
MW-152	12.0	7-12	2402.00
MW-153	9.2	4-9	2402.22
MW-154	30.3	20-30	2401.66
MW-155	9.0	4-9	2402.25
MW-156	39.3	29-39	2405.48
MW-157	36.0	26-36	2401.78
MW-158	89.5	78.2-88.2	2400.82
MW-159	230.0	180-190	2401.20
MW-160	40.0	17-27	2401.88
MW-161	44.4	32-41.6	2401.06
MW-162	39.0	29-39	2401.49
MW-163	180.7	170.7-180.7	2401.49
MW-225	15.8	NA[a/]	2399.36
MW-226	14.7	NA	2399.55
MW-227	15.1	NA	2398.35
ES-GP-1D	16	15.5-16.0	2400.6
ES-GP-2S	10.0	5.0-10.0	2405.0
ES-GP-3D	16.0	15.5-16.0	2405.0
ES-GP-4S	7.5	2.5-7.5	2399.7

[a/] NA = Information not available.

2.1.1 Geoprobe® Operation and Soil Sampling Procedures

The Geoprobe® system is a hydraulically powered percussion/probing machine used to advance sampling tools through unconsolidated soils. This system provides for the rapid collection of soil, soil gas, and groundwater samples at shallow depths while minimizing the generation of investigation-derived waste materials. For Convenience, throughout this report, operation of the Geoprobe® is referred to as "drilling".

2.1.1.1 Pre-Drilling Activities

All subsurface utility lines or other man-made subsurface features were located, and proposed drilling locations were cleared and approved by the Base prior to any drilling activities. Water used in equipment cleaning or grouting was obtained from an onsite potable water supply designated by the Base.

2.1.1.2 Equipment Decontamination and Fluids Handling Procedures

Prior to arriving at the site and between each drilling location, all probe rods, tips, sleeves, pushrods, samplers, tools, and other downhole equipment were decontaminated using an Alconox® detergent and potable water solution followed by a potable water wash. Fittings, tips, and samplers also underwent an additional rinse with isopropyl alcohol followed by a final rinse with deionized water. Precautions were taken to minimize impact to the areas surrounding decontamination operations. All decontamination activities were conducted in a manner so that the excess water was controlled and not allowed to flow into any open borehole.

All decontamination fluids were collected and contained in 55-gallon drums. Following the investigation, the drums were transported to a temporary holding facility designated by the Base. The drums were removed from the Base by ROAR Tech, Inc. for proper treatment and disposal during January 1996.

Fuel, lubricants, and other similar substances were handled in a manner consistent with accepted safety procedures and standard operating practices. All well completion materials were factory sealed and were not stored near or in areas that could be affected by these substances.

2.1.1.3 Drilling and Soil Sampling

Drilling was accomplished using the Geoprobe® direct-push technology. The boreholes were sampled continuously to 10 feet below ground surface (bgs). Thereafter, every second 2-foot interval was sampled to the total depth of the borehole. Where two points were installed adjacent to each other (i.e., nested), only the deeper point was logged and sampled. A final borehole diameter of 2 inches was used for the installation of shallow points with 0.5-inch inside-diameter (ID) casing. For the deep monitoring points, a final borehole diameter of 1 inch was utilized.

The Parsons ES field geologist observed drilling and monitoring point installation activities and maintained a detailed descriptive log of recovered subsurface materials. Final geologic borehole logs are presented in Appendix A. These logs contain:

- Sampled interval (top and bottom depth);
- Presence or absence of contamination based on odor, staining, and/or photoionization detector (PID) readings;
- Soil description, including color, major textural constituents, minor constituents, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, and any other significant observations; and
- Lithologic contacts, with the depth to contacts and/or significant textural changes recorded to the nearest 0.1 foot.

The Geoprobe®-collected soil samples were obtained using 4 foot by 1.5 inch-ID and 2 foot by 1-1/16-inch-ID sampling devices. The large sampler was used for the initial 10 feet of soil. The smaller sampler was then used for the remainder of the borehole in an attempt to minimize the smearing of surface contamination into deeper portions of the borehole. A probe-drive sampler attached to the leading end of the probe rods serves as both the driving point and the sample collection. To collect a soil sample, the sampler was pushed or driven to the desired sampling depth, the drive point was retracted to open the sampling barrel, and the sampler was subsequently pushed into the undisturbed soils. The soil cores were retained within a clear acetate liner inside the sampling barrel. The probe rods were then retracted, bringing the sampling device to the surface. The soil sample was then extruded from the liners for visual lithologic logging and PID headspace screening, or the liners were cut and capped, so that undisturbed samples could be submitted to the analytical laboratory for chemical testing.

Bags containing soil samples collected for the headspace screening procedure were quickly sealed and stored for 15 minutes or longer at the ambient temperature. Semiquantitative measurements were made by puncturing the bag seal with the PID probe and reading the concentration of the headspace gases. The PID relates the concentration of total volatile organic compounds (VOCs) in the sample to an isobutylene calibration standard. The PID also was used to monitor for VOCs in the worker breathing zone.

For soil samples collected for laboratory analysis, the acetate liner was cut into 6-inch lengths, capped, and delivered to the USEPA/NRMRL field personnel for analysis of BTEX, TCE, tetrachloroethene (PCE), and total organic carbon (TOC). For each soil sample the Parsons ES field scientist recorded the following information:

- Sample interval (top and bottom depth);
- Sample identification;

- Sampling date; and,
- Sample collector's initials.

Seven soil samples were collected from areas in the vicinity of the burn pit, oil/water separator, and cross- and upgradient locations. Soil samples were collected immediately above and/or immediately below the water table. Samples for analysis were also selected where PID readings were elevated or visible contamination was present.

2.1.2 Temporary Monitoring Point Installation

Temporary groundwater monitoring points were installed in five boreholes at three locations under this program (Figure 1.2). Detailed monitoring point installation procedures are described in the following paragraphs.

2.1.2.1 Materials Decontamination

Monitoring point completion materials were inspected by the field geologist and determined to be clean and acceptable prior to use. All monitoring point completion materials were factory sealed in plastic wrap. Pre-packaged casing, sand, and bentonite were used in well construction, and were inspected for possible external contamination before use. Materials that could not be cleaned to the satisfaction of the field geologist were not used.

2.1.2.2 Casing and Screen

Upon completion of Geoprobe® sampling to the proper borehole depth, five temporary groundwater monitoring points were installed at three locations. Monitoring point construction details were noted on a monitoring point installation record and are summarized on Table 2.1. This information became part of the permanent field record for the site. Monitoring point installation records for FT-1 are presented in Appendix A.

Two shallow monitoring points (ES-GP-2S and ES-GP-4S), screened across the water table, were constructed of Schedule 40 polyvinyl chloride (PVC) riser pipe and screen having an ID of 0.5 inch. All well casing and screen sections were flush-threaded; glued joints were not used. A sacrificial stainless steel drive point was pressure-fitted into the bottom of the screen using Teflon® tape. Shallow monitoring point screens were 5-feet long and were factory-slotted with 0.010-inch openings.

Two deep temporary monitoring points (ES-GP-1D and ES-GP-3D) screened below the water table and the monitoring point (ES-GPC) in the burn pit were constructed using Teflon®-lined, high-density, polyethylene tubing (HDPE) threaded through the center of the drive rods. The tube was attached to a 0.5-foot-long, 0.375-inch-diameter stainless steel, double-woven wire screen with 0.145-millimeter (0.037-inch) slot size. The screen was threaded into a dedicated stainless steel drive point/implant anchor that

remained in place after the drive rods were removed. Purging and sampling followed directly.

The field geologist recorded the borehole depth, the lengths of all casing sections, and the depth to the top of all monitoring point completion materials placed in the annulus between the casing and borehole wall.

2.1.2.3 Filter Pack and Annular Sealant

Placement of a filter pack around the monitoring point casing screens was not possible as a result of the collapse of the sand borehole walls. Therefore, the temporary monitoring points were naturally sand-packed with the formation materials. Due to the sandy nature of the formation materials, well development and purging activities were accomplished without difficulty.

A filter pack seal of sodium bentonite chips or grout was placed in the portion of the hole which remained open following collapse of the sandy borehole walls. This was typically the top 2 to 3 feet of the borehole.

2.1.2.4 Monitoring Point Abandonment

Following sampling, all five temporary monitoring points were abandoned by removing recoverable construction materials and filling the open hole with bentonite chips. At depth construction materials that could not be recovered were abandoned in place.

2.1.3 Temporary Monitoring Point Development

Prior to sampling, temporary monitoring points were developed. Typically, development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen. Use of the Geoprobe® system to place monitoring points eliminates cuttings and drilling fluids. As a result, development of monitoring points is primarily intended to minimize the amount of fine sediment that might accumulate in the casing.

Monitoring Point development was accomplished using a peristaltic pump with dedicated silicon and HDPE tubing. The pump tubing was regularly lowered to the bottom of the shallow points so that fines were agitated and removed from the point in the development water. Development was continued until 10 casing volumes of water were removed from the point and the groundwater pH, temperature, conductivity, and dissolved oxygen concentrations had stabilized.

2.2 GROUNDWATER SAMPLING

This section describes the procedures used for collecting groundwater samples. In order to maintain a high degree of quality control (QC) during this sampling event, the procedures described in the site work plan (Parsons ES, 1995) and summarized in the following sections were followed.

Groundwater sampling occurred on November 6 through 8, 1995 and on May 30, 1996, and consisted of collecting groundwater samples from temporary monitoring points and from 20 previously installed monitoring wells. Groundwater sampling forms were used to document the specific details of the sampling event for each location. Groundwater samples were analyzed for the parameters listed in Table 2.2. In addition to data from the groundwater sampling conducted under this program, data are available for groundwater sampling events performed at FT-1 in 1986, 1987, 1989 (two sampling events), 1990, 1991 (three sampling events), 1993, and 1995.

Groundwater samples were collected from 25 locations by Parsons ES personnel. Sampling locations are presented on Figure 2.1. Installation and development of the 5 temporary monitoring points was described in Section 2.1. The 20 existing monitoring wells that were sampled under this program included MW-1, MW-2, MW-3, MW-4, MW-49, MW-50, MW-52, MW-53, MW-59, MW-61, MW-100, MW-151, MW-152, MW-153, MW-154, MW-155, MW-156, MW-225, MW-226, and MW-227. Completion data for the temporary monitoring points and previously installed monitoring wells are provided on Table 2.1.

2.2.1 Preparation for Sampling

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) prior to arriving in the field. Special care was taken to prevent contamination of the groundwater and extracted samples through cross contamination from improperly cleaned equipment; therefore, water level indicators and sampling equipment were thoroughly cleaned before and after field use and between uses at different sampling locations. In addition, a clean pair of new, disposable gloves was worn each time a different well/point was sampled.

All portions of sampling and test equipment that contacted the sample were thoroughly cleaned before use. This equipment included the water level probe and cable, equipment for measuring on-site groundwater chemical parameters, and other equipment that contacted the samples. The following cleaning protocol was used:

- Rinse with potable water;
- Rinse with isopropyl alcohol;
- Rinse with distilled or deionized water; and
- Air dry prior to use.

Any deviations from these procedures were documented in the field scientist's field notebook and on the groundwater sampling form. Decontamination fluids were contained and handled as described in Section 2.1.1.2.

As required, field analytical equipment was calibrated according to the manufacturers' specifications prior to field use. Because the majority of physical and chemical analyses were performed by USEPA NRMRL personnel, this requirement

TABLE 2.2
ANALYTICAL PROTOCOL
GROUNDWATER AND SOIL SAMPLES
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

MATRIX Analyte	METHOD	FIELD (F) OR FIXED-BASE LABORATORY (L)
WATER		
Total Iron	Colorimetric, HACH® Method 8008	F
Ferrous Iron (Fe^{2+})	Colorimetric, HACH® Method 8146	F
Ferric Iron (Fe^{3+})	Difference between total and ferrous iron	F
Manganese	Colorimetric, HACH® Method 8034	F
Redox Potential	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	E150.1/SW9040, direct-reading meter	F
Conductivity	E120.1/SW9050, direct-reading meter	F
Temperature	E170.1, direct-reading meter	F
Alkalinity (Carbonate [CO_3^{2-}]	F = Titrimetric, HACH® Method 8221	F
and Bicarbonate [HCO3-])	L = USEPA Method 310.1	L
Nitrate + Nitrite	USEPA Method 353.1	L
Ammonia	USEPA Method 353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane	RSKSOP-147	L
Aromatic Hydrocarbons	RSKSOP-148	L
Fuel Carbon	RSKSOP-148	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
Aromatic Hydrocarbons	RSKSOP-124, modified	L
Total Hydrocarbons	RSKSOP-174	L

applied specifically to direct-reading meters used for onsite chemical measurements of pH, conductivity, and dissolved oxygen (DO).

Upon arrival at the monitoring well/point, the area around the well was cleared of foreign materials, such as brush, rocks, and debris. These procedures prevented sampling equipment from inadvertently contacting debris around the monitoring well. Location preparation also included an inspection of the integrity of the well or monitoring point. At this time, irregularities with the protective cover, cap, lock, external surface seal, internal surface seal, well identification, well datum, and pad were noted.

Prior to removing any water from the well or point, the static water level was measured. In all groundwater wells and temporary PVC monitoring points, an electrical water level probe was used to measure the depth to groundwater below the well datum to the nearest 0.01 foot. Free-phase product (mobile LNAPL) was not detected in any of the wells or points. Water levels could not be obtained from the temporary monitoring points constructed of Teflon®-lined HDPE tubing because the tube diameter is too small to accommodate the water level probe. After measurement of the static water level, the water level probe was lowered to the bottom of the well/monitoring point for measurement of total well depth (recorded to the nearest 0.01 foot). Based on these measurements, the volume of water to be purged from the wells/points was estimated. Static groundwater levels at all site wells also was measured on October 28, 1995, at the start of the field activities.

2.2.2 Well/Point Purging and Sample Collection

The five monitoring points and 13 of the monitoring wells were purged and sampled using a peristaltic pump with dedicated HDPE and silicon tubing. Dedicated bladder pumps were used to purge and sample the 7 wells equipped with such pumps (MW-1, MW-3, MW-50, MW-100, MW-151, MW-152, and MW-154). Purging consisted of removing at least three times the calculated casing volume prior to sample collection. Once three casing volumes of water were removed from the well/point purging continued until the pH, DO concentration, conductivity, and temperature stabilized.

Within 24 hours of the purge event, groundwater samples were collected from the monitoring wells/points. The samples were transferred directly from the peristaltic or bladder pump discharge tubing into the appropriate sample containers. The water was carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Sample bottles for BTEX, trimethylbenzenes (TMB), chlorinated solvents, and dissolved gas analyses were filled so that there was no headspace or air bubbles within the container. Table 2.2 lists the analyses performed on collected groundwater samples.

2.2.3 On-site Chemical Parameter Measurement

Measurement of DO, pH, specific conductance, and temperature was performed at the sampling location at the time of sample collection. All other field parameters were

measured onsite by USEPA NRMRL personnel at their mobile laboratory immediately following sample collection.

DO measurements were taken using an Orion® model 840 DO meter in a flow-through cell at the discharge of the peristaltic or bladder pump. DO concentrations were recorded after the readings stabilized, and in all cases represent the lowest DO concentration observed.

Because the pH and temperature of the groundwater can change significantly within a short time following sample acquisition, these parameters were measured in the field, in the same flow-through cell used for DO measurements. The measured values were recorded on the groundwater sampling record.

Specific conductance measurements were taken using an EXTECH® Oyster meter in the same flow-through cell in which DO was measured. The conductance was recorded on the groundwater sampling record.

2.2.4 Sample Handling

The USEPA/NRMRL personnel provided appropriately preserved sample bottles. Samples were delivered to the USEPA mobile laboratory within minutes of sample collection. Because ambient temperatures were cool and the samples were delivered to the mobile laboratory within minutes of sample collection, ice was not used to cool the samples during transport to the USEPA mobile laboratory. Samples for those analyses not performed by the mobile laboratory were appropriately package and shipped by the USEPA field personnel to the NRMRL in Ada, Oklahoma for analysis. The associated chain-of-custody documentation for the fixed base laboratory was the responsibility of the USEPA NRMRL field personnel.

The sample containers were filled as described in Section 2.2.3, and the container lids were tightly closed. The sample label was firmly attached to the container side, and the following information was legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (groundwater);
- Sampling date;
- Sampling time;
- Preservatives added; and

Sample collector's initials.

After the samples were sealed and labeled, they were transported to the onsite USEPA mobile laboratory. Samples were packaged to prevent leakage or vaporization from the containers, and the samples were cushioned to avoid breakage.

2.3 AQUIFER TESTING

Slug tests were conducted at eight monitoring well locations to estimate the hydraulic conductivity of the shallow saturated zone at FT-1. Slug tests are single-well tests used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft2/day). Slug testing can be performed using either a rising-head or a falling-head test. Both rising-head and falling-head tests were used at this site. The tests were performed in monitoring wells MW-1, MW-3, MW-151, MW-153, MW-155, MW-225, MW-226, and MW-227 (Figure 2.1). Detailed slug testing procedures are presented in the Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater (Wiedemeier et al., 1995), hereafter referred to as the technical protocol document.

Data obtained during slug testing were analyzed using AQTESOLV® software and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The results of slug testing are presented in Section 3.3 and Appendix A.

2.4 SURVEYING

After completion of field work, the locations and elevations of temporary monitoring points and sampled monitoring wells were surveyed by David Evans and Associates of Spokane, Washington. The horizontal locations were measured relative to the Fairchild AFB 1984 coordinate survey. The vertical elevations of the ground surface adjacent to the well/point casing and the measurement datum (top of the PVC well/point casing) were measured relative to existing survey control points tied into the United States Geological Survey (USGS) 1929 coordinate system. Horizontal location was surveyed to the nearest 0.1 foot. Datum and ground surface elevations were surveyed to the nearest 0.01 foot.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of Site FT-1 as determined from data collected by Parsons ES in November 1995 and May 1996, in conjunction with data documented in previous reports on FT-1 and Fairchild AFB. Investigative techniques used by Parsons ES to determine the physical characteristics of the site are discussed in Section 2.

3.1 SURFACE FEATURES

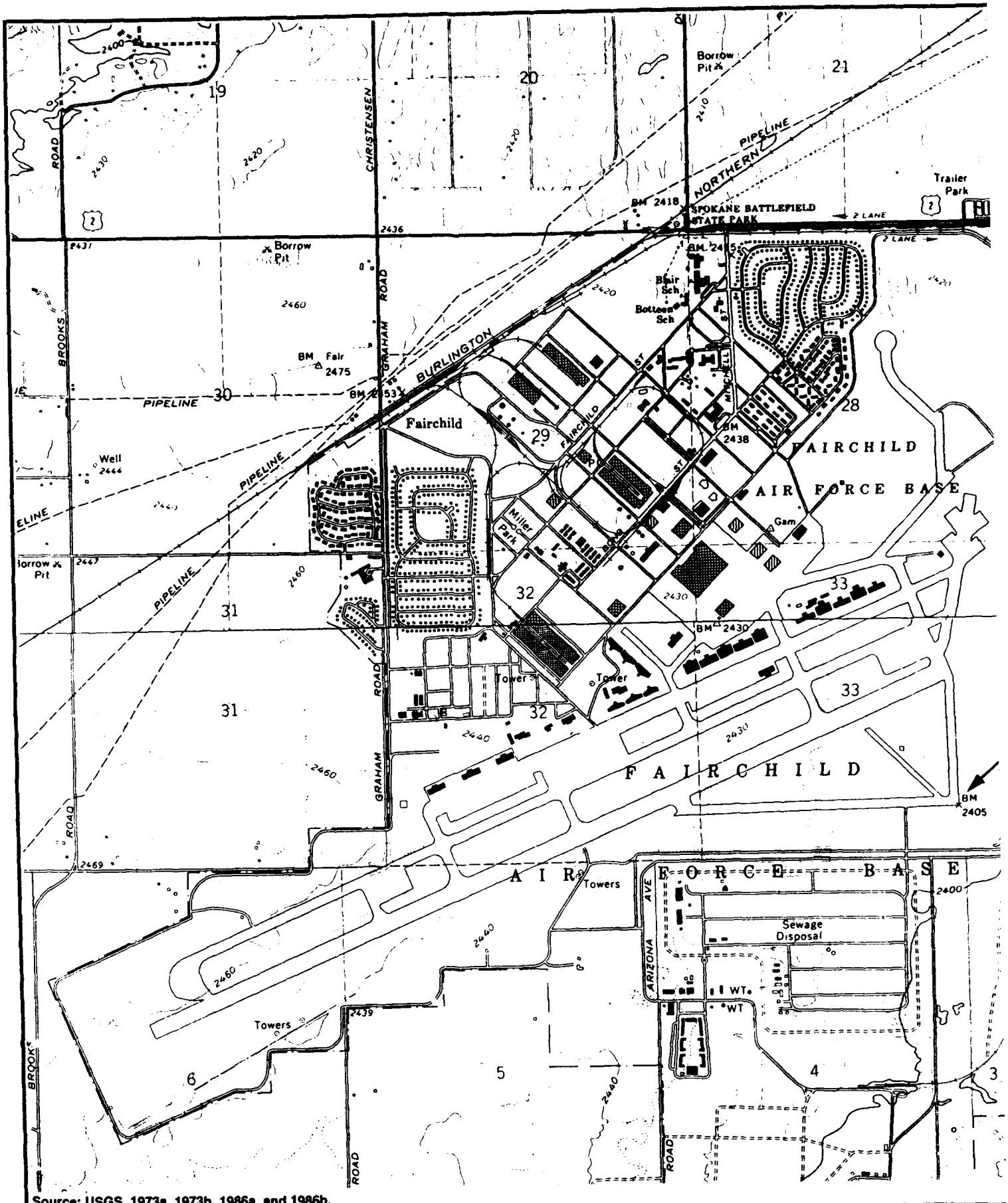
3.1.1 Topography

Fairchild AFB is located within the Columbia Basin in the northeastern corner of the 55,000-square-mile Columbia Plateau Physiographic Province (ICF Technology Inc., 1995). The Columbia Plateau is bordered by mountains and highlands on all sides. The northern edge of the Plateau gives way to the Okanogan Highlands roughly 75 miles north of Fairchild AFB, while the eastern end of the Plateau is bordered by the Rocky Mountains, approximately 75 miles east of Fairchild AFB. The Plateau extends approximately 250 miles to the south and west of the Base. The Blue Mountains border the Plateau on the south, and the Cascade Mountains border the Plateau on the west. There is a watershed divide in the center of the Plateau that causes streams north of this divide to flow in a northerly direction, and streams south of the divide to flow in a southerly direction. The topography of the region was shaped by glacial flood waters that eroded the surface of the Columbia Plateau during the Pleistocene Epoch (approximately 22,000 years ago) (HNUS, 1993b).

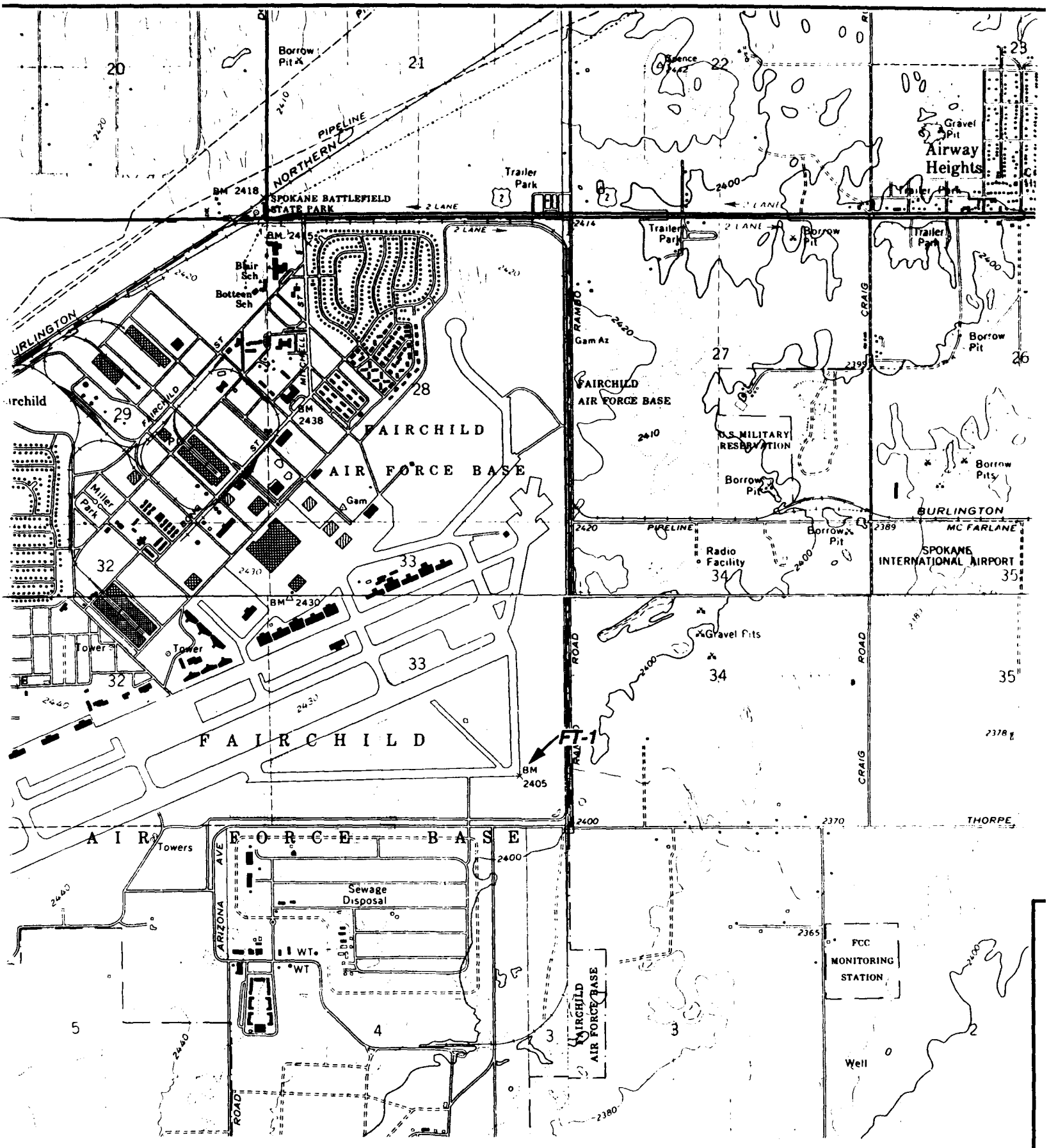
The surface topography of the Base and surrounding region is generally flat to gently rolling grasslands sloping slightly to the east-northeast. Ground surface elevations on the Base range from 2,400 to 2,460 feet above mean sea level (ft msl) (Figure 3.1).

3.1.2 Surface Water Hydrology

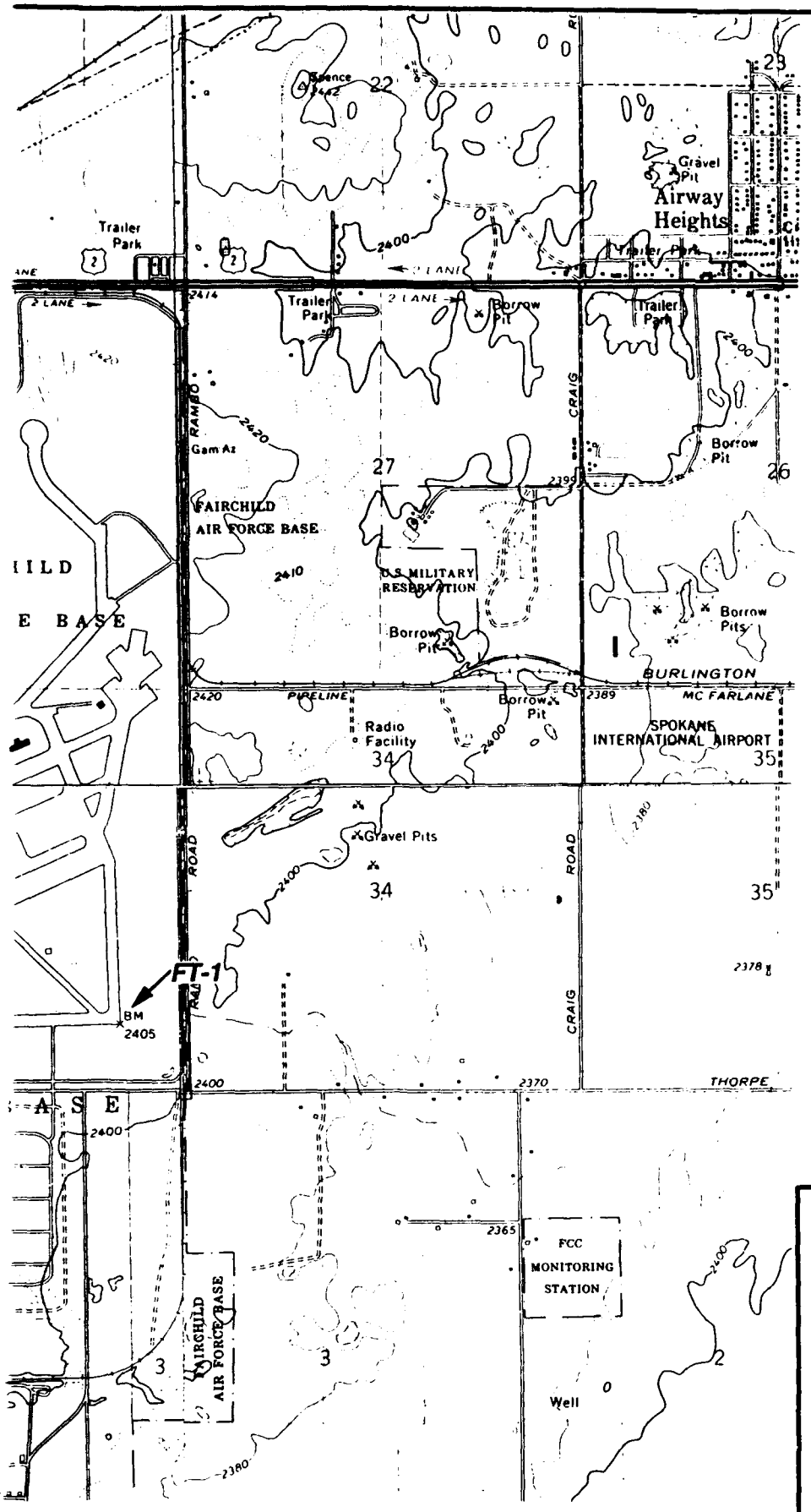
Fairchild AFB is located in the northern half of the Columbia Plateau, north of the watershed divide. All surface water drainage in this region of the Columbia Plateau generally flows to the north or northwest (Flint, 1936). The Base is approximately 7 miles west-southwest of the Spokane River, which flows through the city of Spokane (USGS, 1973a, 1973b, 1986a, and 1986b). Two other drainages in the vicinity of the Base are Deep Creek and Marshall Creek, located approximately 2 miles northwest and 8 miles southeast of the Base, respectively. These creeks flow northwest and join the

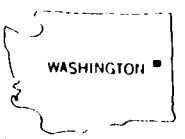


Source: USGS, 1973a, 1973b, 1986a, and 1986b.



Borrow Pit
20
21
22
23
Spence
Gravel Pit
Airway Heights
Trailer Park
NORTHERN PIPELINE
BM 2418
SPOKANE BATTLEFIELD STATE PARK
2 LANE
BM 2415
Blair Sch
Botteen Sch
BURLINGTON
Trailer Park
Borrow Pit
Gam Az
RAMBO
CRAIG
Borrow Pit
26
27
FAIRCHILD AIR FORCE BASE
U.S. MILITARY RESERVATION
Borrow Pits
BURLINGTON
PIPELINE
MC FARLANE
Radio Facility
SPOKANE INTERNATIONAL AIRPORT
28
29
BM 2438
FAIRCHILD AIR FORCE BASE
Miller Park
Gam
32
33
34
35
BM 2430
Tower
Gravel Pits
ROAD
FT-1
BM 2405
FAIRCHILD AIR FORCE BASE
Towers
THORPE
Sewage Disposal
ARIZONA AVE
WT
FCC MONITORING STATION
FAIRCHILD AIR FORCE BASE
5
4
3
2
Well





QUADRANGLE LOCATION

FIGURE 3.1

REGIONAL TOPOGRAPHIC BASE MAP

Site FT-1
Remediation by Natural Attenuation
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Spokane River, which drains this region of the Plateau. Surface water on the Base is generally limited to precipitation runoff and intermittent flow in No Name Ditch near the eastern boundary of the Base just north of FT-1 (Figure 2.1). Precipitation runoff is controlled within a series of manmade ditches. Reportedly, water collected in the ditch system does not leave Base property, and surface water either infiltrates the subsurface or evaporates (HNUS, 1993b).

At FT-1, storm precipitation is reported to infiltrate into the ground. A manmade drainage ditch extends approximately 300 feet eastward from the oil/water separator on the eastern edge of the training pit and terminates in a broad, flat marshy area (Figure 2.1). The oil/water separator treated discharge generated during fire training exercises. Fire training exercises ceased at the site in 1991, and the oil/water separator is currently inactive. Snow melt runoff was observed in the ditch during the RI activities (HNUS, 1993b).

3.1.3 Manmade Features

FT-01 is located adjacent to an abandoned aircraft taxiway in a relatively undeveloped portion of the Base that is mostly vegetated with grasses. Manmade features at the site include a fire training pit, a two-story fire training building, an equipment shed for the bioventing and air sparge pilot tests, and an abandoned underground oil/water separator with a 300-foot buried discharge line from the separator (Figure 1.2). All of these features are located on a 600-foot wide gravel pad that is elevated above the surrounding marshy area and is flush with the adjacent taxiway. At the eastern and southern boundaries of the site are a gravel perimeter road, a chainlink security fence, and Rambo and Thorpe Roads. West and north of the site, beyond the taxiway, are the active runway and flightline.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

The shallow subsurface geology at Fairchild AFB is a mixture of Quaternary sediments consisting of eolian, glacial, fluvial, lacustrine deposits. Flood waters from the glacial-era Missoula Lake scoured the basalt bedrock of this region of the Columbia Plateau. Coarse sediments were deposited during the early recession of flood waters, followed by finer sediments during the later stages of floodwater recession. The alluvium in the vicinity of the Base generally consists of fine-grained sediments deposited by receding glacial flood waters. Clays and silts are intermixed with sandy silts, clays, and gravels (HNUS, 1993b). In addition, loess (windblown silt) deposits are interbedded in portions of the unconsolidated deposits. Unconsolidated deposits generally follow the slope of the underlying basalt bedrock (ICF Technology, Inc., 1995).

Bedrock in the vicinity of the Base is mostly Tertiary basalts of the Columbia River Group. Basalts below Fairchild AFB are of the Wanampum Formation (HNUS, 1993b). The basalt flows in the region are interbedded with sedimentary clay and silt units of the Latah Formation. These layers were deposited when stream beds were isolated by the volcanic basalt flows (Cline, 1969). The Wanampum Basalt flow below

the Base appears to be divided into upper and lower flow sequences by an interbed of the Latah Formation. The upper basalt flow is 166 feet to 193 feet thick across the Base. The surface of the upper basalt flow is vesiculated, deeply fractured, and highly weathered in places. Just east of the Base the upper basalt layer was completely eroded away by the Missoula Lake flood waters. The middle of this flow contains few vesicles and fractures; the formation becomes more massive and competent with depth. The underlying Latah Formation deposits consist of an extensive silty claystone that ranges in thickness from 8.5 to 10 feet (HNUS, 1993b). Information on the geologic characteristics of the lower basalt flow was not available in the previous reports reviewed as part of this investigation. However, this unit is isolated from the overlying units; therefore, its geologic characteristics are not pertinent to FT-1 site characterization.

Groundwater in the vicinity of the Base is encountered from 8 to 12 feet bgs and is found in both the unconsolidated material and the underlying basalt bedrock. Recharge of the surficial aquifer under the Base is expected to come from upgradient flow and surface runoff infiltration. Groundwater flow in the unconsolidated deposits is through intergranular pore space, while flow in the basalt is through interconnecting fractures (HNUS, 1993b). Flow across the Base is generally to the east and east-northeast, but local variations may result from local changes in bedrock topography. Groundwater in the unconsolidated material and shallow bedrock is generally unconfined, with some local semiconfined areas. The unconsolidated material and the shallow basalt are hydraulically connected by fractures, vesicles, and weathered zones. The middle region of the shallow basalt flow is more competent with less fracturing, and acts as an aquitard. The interbedded claystone between the basalt flows also acts as a confining layer (HNUS, 1993b).

3.3 SITE GEOLOGY AND HYDROGEOLOGY

Characterization of the Quaternary sediments and Tertiary basalts at FT-1 has been the objective of several investigations; the site geology and hydrogeology descriptions presented below were principally derived from the site RI (HNUS, 1993b) and the current investigation. There are currently 39 groundwater monitoring wells associated with FT-1, including 21 wells screened in the unconsolidated deposits and 18 wells screened in the basalt bedrock. As part of the current investigation, five monitoring points were installed at four locations using a Geoprobe®.

3.3.1 Lithology and Stratigraphic Relationships

Surface soils at the site primarily consist of Cheney and Uhlig Series clayey silts, and the description of subsurface soils underlying FT-1 is relatively consistent with the regional geology described in Section 3.2. Unconsolidated material overlying the basalt bedrock ranges in thickness from 9 feet to 30 feet across the site. Shallow deposits at FT-1 are primarily silty clays and clayey silts with sands, while deeper unconsolidated material appears to be coarser grained and consists of silty sands and gravels containing occasional basalt fragments. Unconsolidated material overlies two distinct basalt flows that are separated by a Latah Formation sedimentary interbed. A

layer of gray to black gravel and coarse sand fill up to 2 feet thick covers the area designated in Figure 3.2 as the gravel pad.

Geologic features of the shallow basalt flow, sedimentary interbed, and upper portion of the deeper basalt flow underlying FT-1 were investigated during the installation of a cored hole later completed as MW-159 (HNUS, 1993b). The shallow basalt flow is estimated to be 192 feet thick and to extend to a depth of 207 feet bgs. The upper 50 feet of the shallow basalt flow is described as being massive weathered basalt with small vesicles and slight to moderate fracturing. The middle portion of the upper basalt flow becomes more dense with fewer vesicles and hairline fractures existing from 65 to 180 feet bgs. From 180 feet to 205 feet bgs, the flow is described as relatively nonfractured and nonvesicular massive basalt. The bottom few feet of the upper basalt flow, near the Latah interbed, becomes more vesicular. The Latah Formation interbed separating the upper and lower basalt flows is approximately 8.5 feet thick and extends from 207 feet bgs to 215.5 feet bgs. This interbed consists of silty claystone with deposits of organic material. The upper portion of the deep basalt flow is described as highly vesicular with a moderate to high number of fractures and minor weathering. Deeper portions of the lower basalt flow had not been investigated in reports reviewed during the development of this work plan.

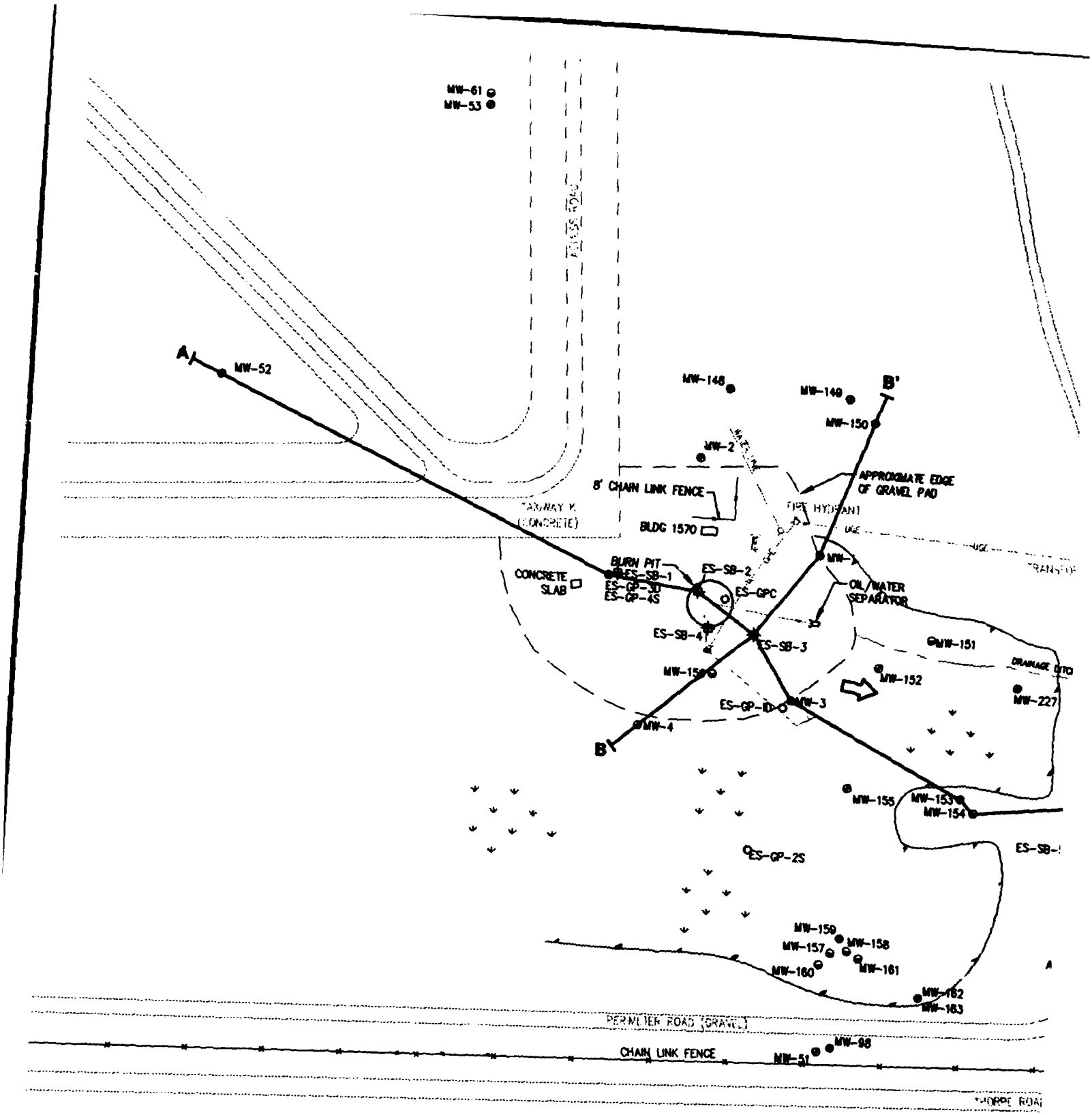
To illustrate these stratigraphic relationships, hydrogeologic sections have been developed from subsurface data derived from logs of previously installed monitoring wells and from the November 1995 Geoprobe® investigation. Geologic sections A-A' and B-B' depict the unconsolidated material and shallow regions of the upper basalt bedrock underlying the site. Figure 3.2 shows the locations of these sections. Figure 3.3 presents hydrogeologic section A-A', which is approximately parallel to the direction of groundwater flow. Figure 3.4 presents hydrogeologic section B-B', which is approximately perpendicular to the direction of groundwater flow.

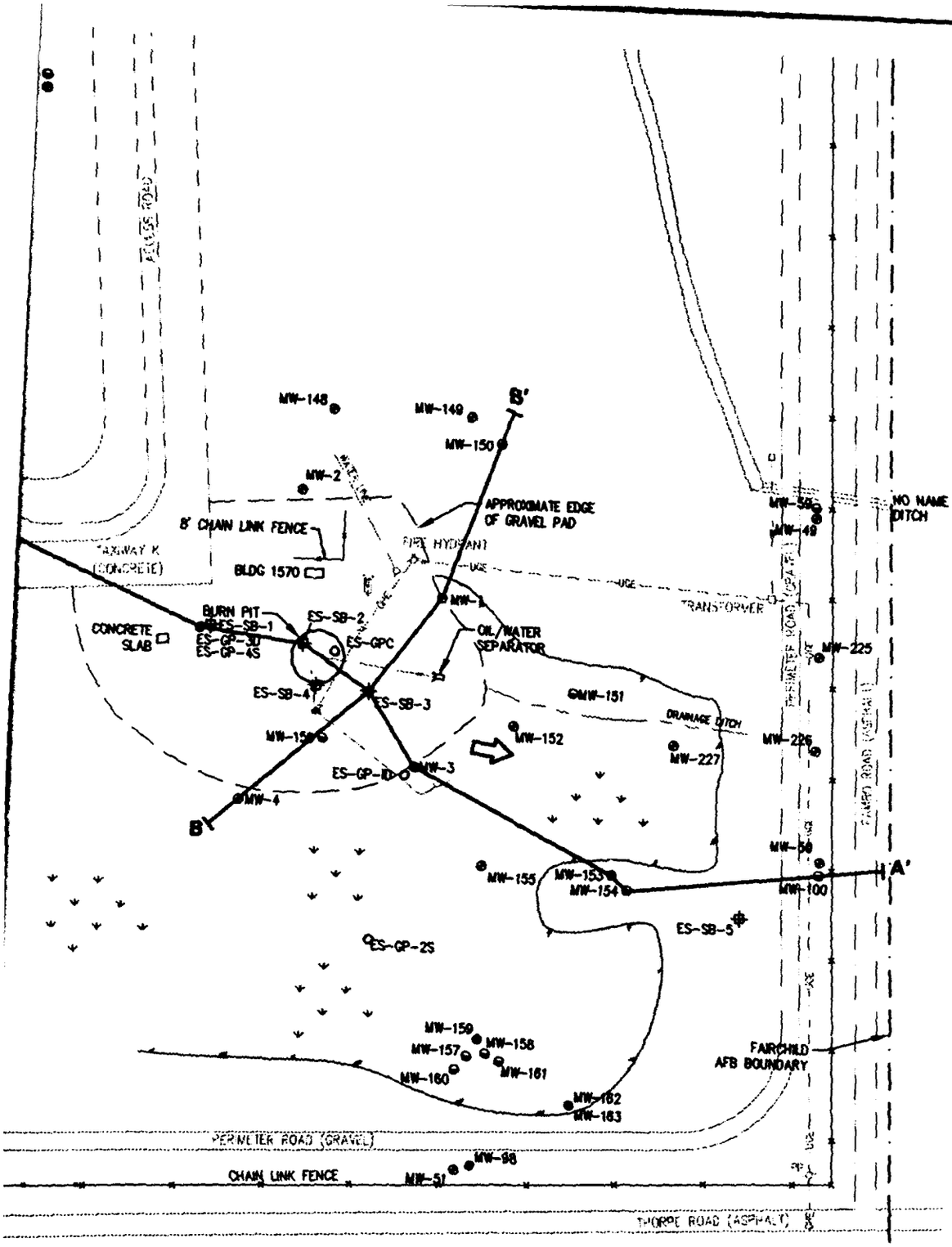
3.3.2 Groundwater Hydraulics

Shallow groundwater at the site resides in the Quaternary glacial deposits and in the underlying upper basalt bedrock. Depth to groundwater is approximately 5 to 7 feet bgs across the majority of the site. A summary of groundwater measurements from November 1995 is presented in Table 3.1. A summary of select historical groundwater elevation data is provided in Appendix A.

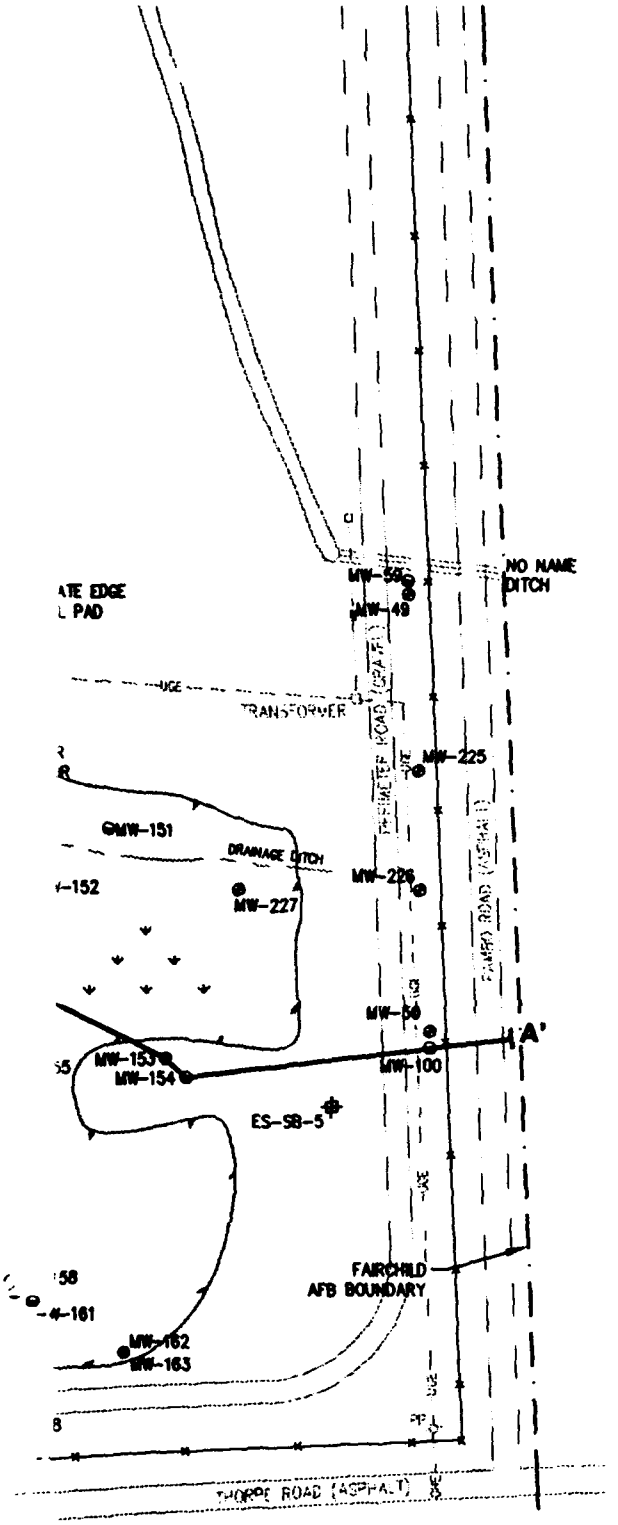
3.3.2.1 Flow Direction and Gradient

In the immediate vicinity of the site, groundwater flows to the east-southeast, which is similar to the regional flow direction. Figure 3.5 shows the groundwater surface for FT-1 in November 1995. The hydraulic gradient at the site decreases from approximately 0.008 foot per foot (ft/ft) in the burn pit to approximately 0.002 ft/ft through the marshy area immediately downgradient from the source area. This is consistent with historic groundwater gradients. For example, groundwater elevations measured in March 1992 indicate the average hydraulic gradient across FT-1 was approximately 0.002 ft/ft; however, the hydraulic gradient in the source area and


MW-61
MW-53
MW-52
A
A'
B
B'
MW-148
MW-149
MW-150
MW-2
8' CHAIN LINK FENCE
APPROXIMATE EDGE OF GRAVEL PAD
FIRE HYDRANT
BLDG 1570
TAXIWAY K (CONCRETE)
BURN PIT
ES-SB-1
ES-GP-3D
ES-GP-4S
ES-SB-2
ES-GPC
CONCRETE SLAB
OIL/WATER SEPARATOR
MW-1
ES-SB-4
ES-SB-3
MW-151
MW-152
MW-227
MW-158
MW-3
ES-GP-1D
MW-4
MW-155
MW-153
MW-154
ES-GP-2S
MW-159
MW-157
MW-158
MW-160
MW-161
MW-162
MW-163
PERIMETER ROAD (GRAVEL)
CHAIN LINK FENCE
MW-98
MW-51



MW-148
MW-149
B'
MW-150
MW-2
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
FIRE HYDRANT
TAXIWAY K (CONCRETE)
BLDG 1570
UGE
TRANSFORMER
NO NAME DITCH
MW-49
BURN PIT
ES-SB-1
ES-SB-2
CONCRETE SLAB
ES-GP-3D
ES-GP-4S
ES-GPC
OIL/WATER SEPARATOR
MW-225
ES-SB-4
ES-SB-3
MW-151
DRAINAGE DITCH
MW-152
MW-226
MW-227
ES-GP-1D
MW-3
MW-4
B
MW-155
MW-153
MW-154
MW-100
A'
ES-SB-5
ES-GP-2S
MW-159
MW-158
MW-157
MW-161
MW-160
FAIRCHILD AFB BOUNDARY
MW-162
MW-163
PERIMETER ROAD (GRAVEL)
MW-98
CHAIN LINK FENCE
MW-51
THORPE ROAD (ASPHALT)



LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- TEMPORARY MONITORING AND SOIL SAMPLING LOCATION
- SOIL SAMPLING LOCATION
- A——A' LOCATION OF HYDROGEOLOGIC SECTION
- APPROXIMATE GROUNDWATER FLOW DIRECTION

0 100 200 400

FEET

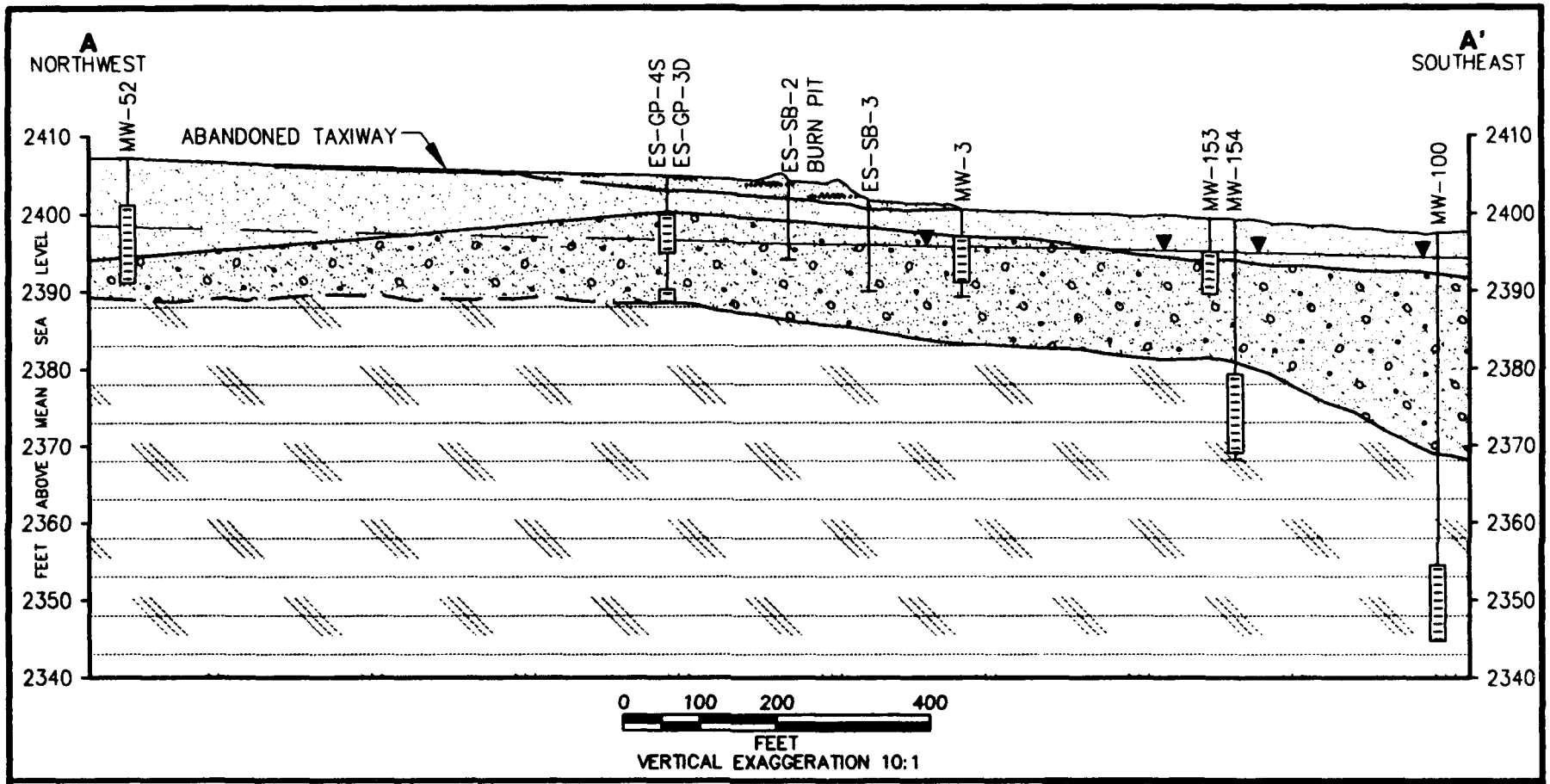
FIGURE 3.2

HYDROGEOLOGIC SECTION LOCATIONS

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado



LEGEND

- GRAVELLY SAND, GRAY, FILL
- SILTY SAND, DARK BROWN, SOME GRAVEL
- SAND AND GRAVEL, BROWN, ISOLATED BASALT FRAGMENTS
- BASALT
- WATER LEVEL 11/95 (DASHED WHERE APPROXIMATE)
- MW-3 — MONITORING WELL ID
- SCREENED INTERVAL
- TOTAL DEPTH OF BOREHOLE

FIGURE 3.3

HYDROGEOLOGIC SECTION A-A'

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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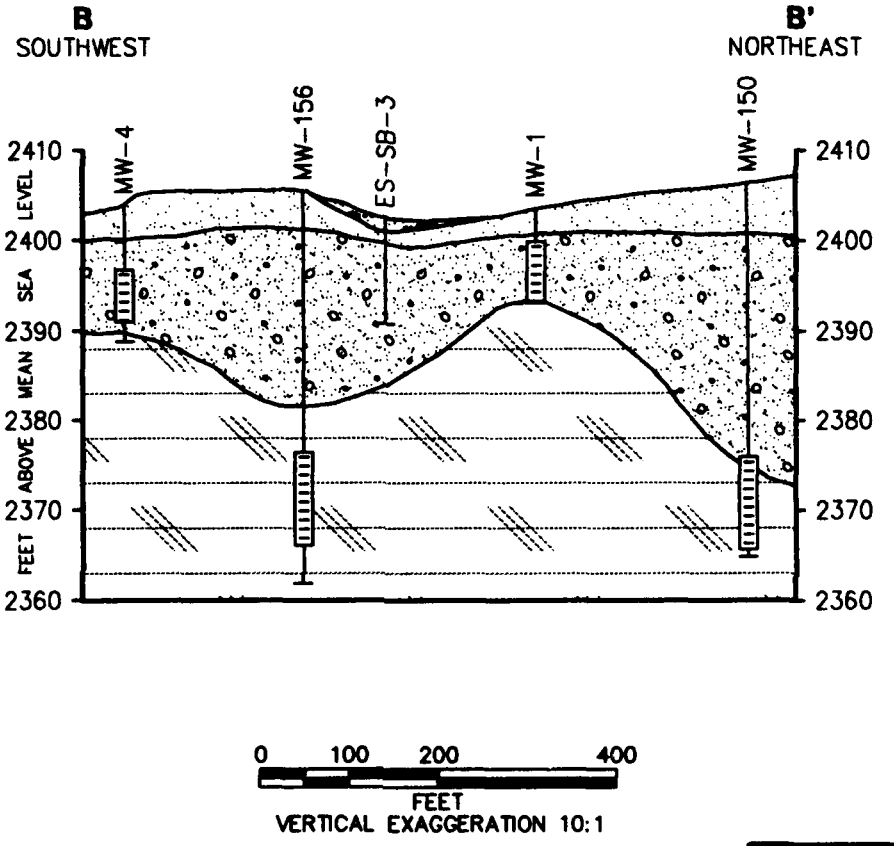

FIGURE 3.4

HYDROGEOLOGIC SECTION B-B'

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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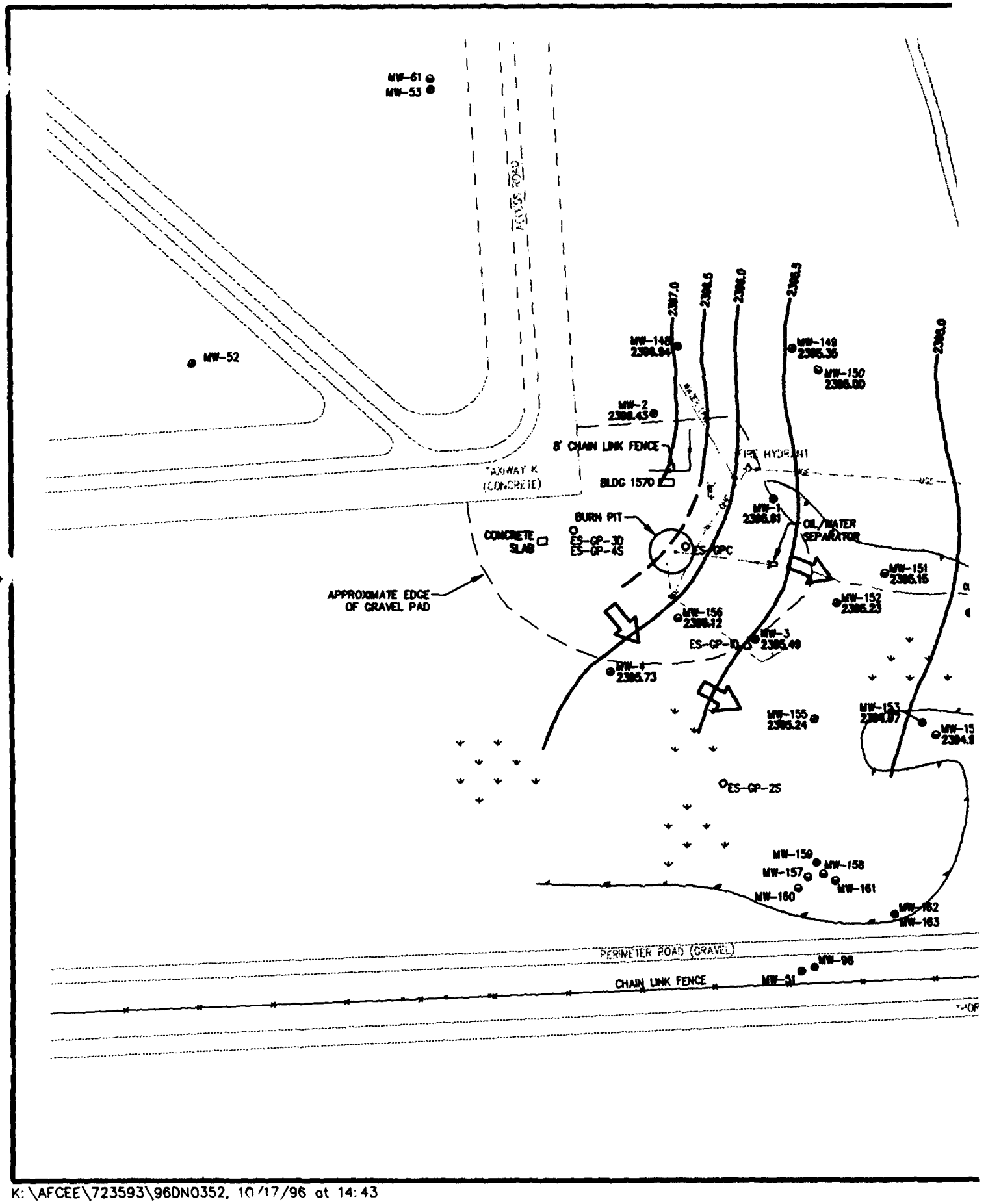
TABLE 3.1
SUMMARY OF GROUNDWATER ELEVATION DATA
NOVEMBER 1995
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Well Identification	Elevation of Reference Point for Measurements (feet msl)[a/]	Depth to groundwater groundwater (feet)	Groundwater Elevation (feet msl)
MW-1	2404.10	8.49	2395.61
MW-2	2405.79	6.36	2399.43
MW-3	2403.61	6.54	2397.07
MW-4	2404.64	8.91	2395.73
MW-49	2401.18	6.81	2394.37
MW-50	2400.11	5.38	2394.73
MW-98	2400.35	97.03	2303.32
MW-100	2400.60	6.03	2394.57
MW-148	2407.09	10.15	2396.94
MW-149	2407.06	11.71	2395.35
MW-150	2406.88	10.88	2396.00
MW-151	2400.53	5.38	2395.15
MW-152	2402.00	6.77	2395.23
MW-153	2402.22	7.25	2394.97
MW-154	2401.66	6.71	2394.95
MW-155	2402.25	7.01	2395.24
MW-156	2405.48	9.36	2396.12
MW-157	2401.78	6.61	2395.17
MW-158	2400.82	8.02	2392.80
MW-160	2401.88	7.71	2394.17
MW-161	2401.06	5.98	2395.08
MW-225	2399.36	4.78	2394.58
MW-226	2399.55	4.78	2394.77
MW-227	2398.35	3.40	2394.95

[a/] Feet msl = feet above mean sea level.



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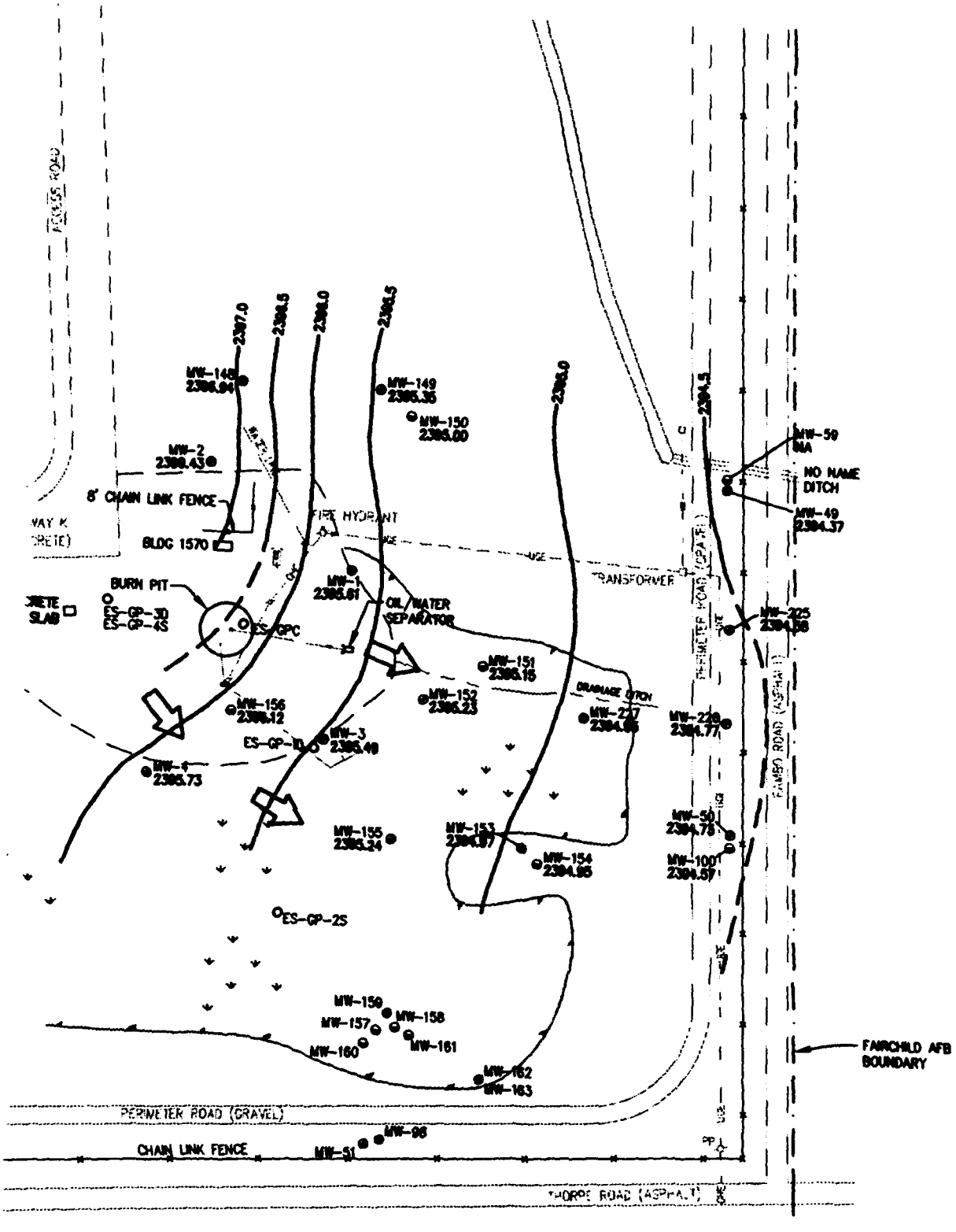

NOTE:
CONTOUR
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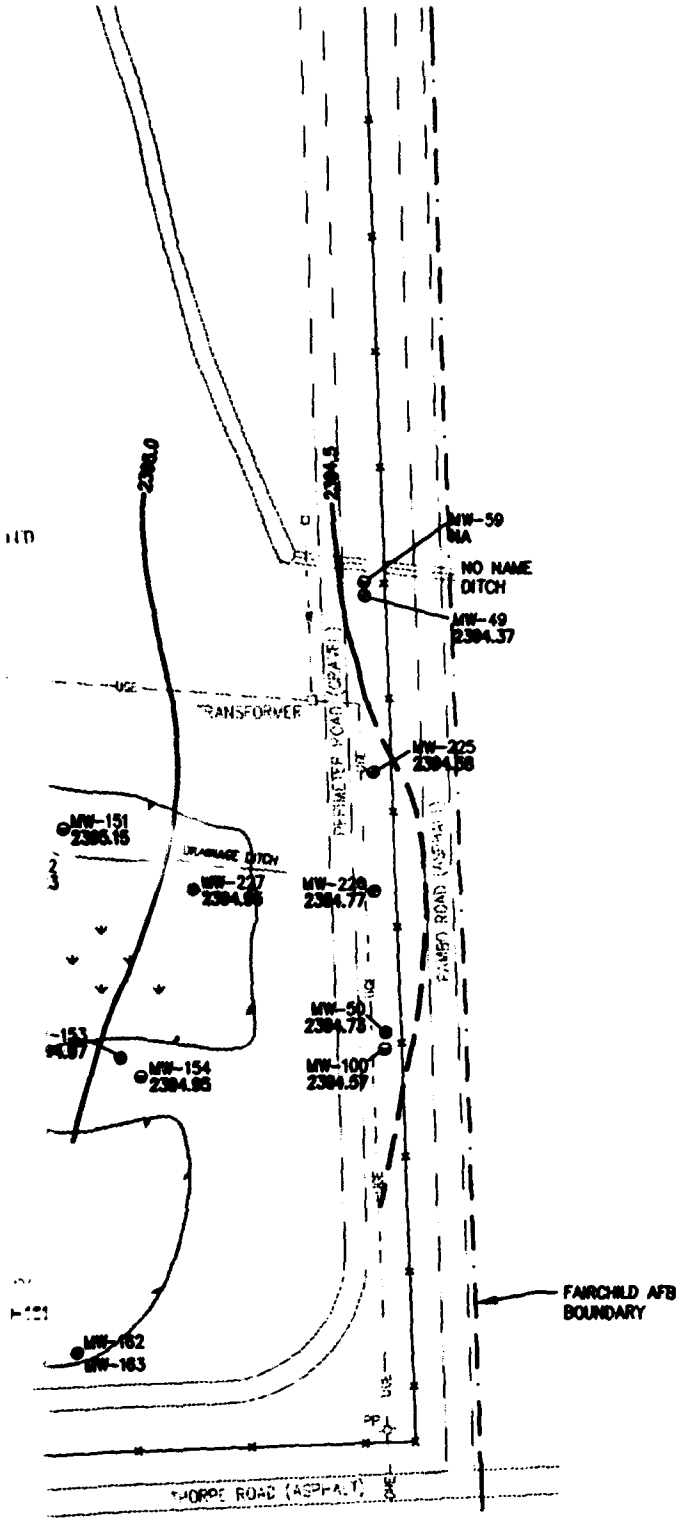


LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- TEMPORARY MONITORING POINT

2396.12 GROUNDWATER ELEVATION (FEET ABOVE MEAN SEA LEVEL)

LINE OF EQUAL GROUNDWATER ELEVATION (FEET ABOVE MEAN SEA LEVEL) (DASHED WHERE INFERRED)

APPROXIMATE GROUNDWATER FLOW DIRECTION

CONTOUR INTERVAL = 0.5 FOOT

NOTE:

CONTOURED ON THE BASIS OF GROUNDWATER ELEVATIONS MEASURED AT SHALLOW MONITORING WELLS.

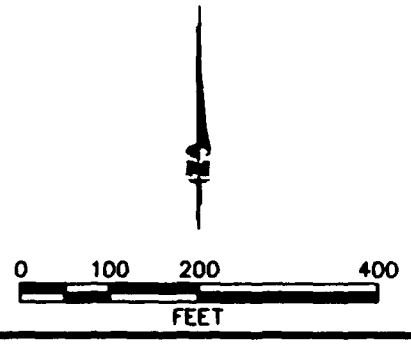


FIGURE 3.5

SHALLOW GROUNDWATER CONTOUR MAP (NOVEMBER 1995)

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

immediately east of Rambo Road was somewhat steeper, at 0.007 ft/ft (HNUS, 1993b). Fluctuations of up to 9 feet were observed in monitoring well data collected from February 1991 to April 1992 (HNUS, 1993b). Typically, groundwater elevations at Fairchild AFB are lower during August through November, and higher during April through July (ICF Technology, Inc., 1995).

Three unconsolidated deposit/shallow bedrock groundwater monitoring well pairs (MW-149/MW-150; MW-50/MW-100; and MW-153/MW-154) were used to evaluate vertical hydraulic gradients and the vertical extent of contamination in groundwater underlying FT-1. Groundwater elevation data collected in 1991 and 1992 suggest downward vertical gradients of 0.01 and 0.006 ft/ft for monitoring well pairs MW-149/MW-150 and MW-50/MW-100, respectively. Water elevations measured in groundwater monitoring wells MW-154 and MW-153 did not indicate the presence of a vertical gradient near this pair (HNUS, 1993b). In October 1995, downward vertical gradients of 0.004 and 0.001 ft/ft were measured at well pairs MW-50/MW-100 and MW-153/MW-154, respectively. One upward gradient of 0.026 ft/ft was measured at monitoring well pair MW-149 and MW-150. These observations suggest that, in general, groundwater is in communication between the unconsolidated deposits and shallow bedrock, and that it experiences a slight downward gradient.

The maximum downward vertical gradient between nested wells screened in the shallow bedrock and unconsolidated deposits was 0.58 ft/ft measured in 1992 between upgradient wells MW-53 and MW-61 (Figure 3.5). Basalt bedrock well MW-61 exists in a high-yielding fracture zone. Because of the large differences in hydraulic heads between well MW-61 and the nearby unconsolidated deposit well (MW-53) and other site wells screened between 60 and 70 feet bgs in the basalt bedrock, it is believed that the fracture zone at MW-61 is hydraulically isolated from other site wells of similar or shallower depth.

Large differences in groundwater elevations were observed between all well pairs screened in the shallow bedrock and in the deeper regions of the upper basalt flow. In 1992, groundwater elevations measured in deep bedrock monitoring wells MW-159, MW-98, and MW-163 were 172 feet, 80 feet, and 169 feet lower, respectively, than measurements collected from MW-51, the nearest shallow well. In 1995, the groundwater elevation at monitoring well MW-98 was about 90 feet lower than the shallow measurements across the site. These differences appear to indicate that groundwater in the unconsolidated deposits and the shallow bedrock is not in communication with groundwater in deeper regions of the bedrock.

3.3.2.2 Hydraulic Conductivity

In November 1995, Parsons ES estimated the hydraulic conductivity at wells MW-1, MW-3, MW-151, MW-153, MW-155, MW-225, MW-226, and MW-227 using falling- and rising-head slug tests and the method of Bouwer and Rice (1976) as described in Section 2. The maximum, minimum, and average hydraulic conductivities estimated from multiple rising and falling head slug tests performed at each of the eight slug test locations are provided in Table 3.2. Average hydraulic conductivities ranging

TABLE 3.2
1995 SLUG TEST RESULTS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

WELL	MINIMUM HYDRAULIC CONDUCTIVITY (ft/day)	MAXIMUM HYDRAULIC CONDUCTIVITY (ft/day)	AVERAGE HYDRAULIC CONDUCTIVITY (ft/day)
MW-1	17.8	20.9	19.7
MW-3	22.9	24.9	23.8
MW-151[a/]	1.74	2.32	2.07
MW-153	8.08	42.4	24.0
MW-155	8.93	19.2	15.3
MW-225	5.65	29.1	15.5
MW-226	3.23	33.4	18.4
MW-227	0.12	0.32	0.19

[a/] Monitoring well is screened in the shallow bedrock.

from 15.3 to 24.0 (ft/day) were estimated for six of the seven wells screened across the water table at FT-1. Monitoring well MW-227, also screened across the water table, had an estimated hydraulic conductivity of 0.19 ft/day. The average hydraulic conductivity of the sands in the shallow saturated zone as determined from these tests is approximately 19.7 ft/day. A hydraulic conductivity of 2.07 ft/day was estimated for the shallow bedrock using November 1995 slug test data collected at monitoring well MW-151.

Previously, site hydraulic conductivities and transmissivities had been estimated from pumping tests (HNUS, 1993b). Pumping tests were performed in the unconsolidated material monitoring wells MW-1 and MW-155, both of which are screened across gravelly sand deposits. The hydraulic conductivities calculated from the pump test data are 418 ft/day at MW-1 and 37 ft/day at MW-155. Transmissivities were calculated at 2,410 ft^2/day and 214 ft^2/day at wells MW-1 and MW-155, respectively (HNUS, 1993b). An additional pumping test was performed in shallow bedrock well MW-157. The average hydraulic conductivity and average transmissivity of the shallow basalt were calculated as 0.8 ft/day and 21.8 ft^2/day, respectively.

Although attempted, pumping tests were not completed in the deeper regions of the upper basalt flow because sufficient pumping rates could not be sustained in installed pumping wells, implying that hydraulic conductivity is much lower through this interval (HNUS, 1993b). Decreasing hydraulic conductivity in the upper basalt bedrock also was computed from packer tests performed during installation of monitoring well MW-159. Within the upper basalt, computed hydraulic conductivities were 2.56 to 2.66 ft/day at 20 to 35 feet bgs, 0.01 to 0.09 ft/day at 35 to 135 feet bgs, 0.30 to 0.34 ft/day at 135 to 195 feet bgs, and 0.52 to 0.58 ft/day at 197 to 207 feet bgs. The silty claystone of the Latah formation (207 to 215 feet bgs) had a hydraulic conductivity of 0.60 ft/day, and the upper portion of the lower basalt (216 to 227 feet bgs) had a hydraulic conductivity range of 0.52 to 0.82 ft/day.

3.3.2.3 Effective Porosity

Because of the difficulty involved in accurately determining effective porosity, accepted literature values for the type of soil making up the shallow saturated zone were used. Walton (1988) gives ranges of effective porosity for medium to coarse sand of 0.15 to 0.35. An average effective porosity of 0.25 was assumed for this project.

3.3.2.4 Advective Groundwater Velocity

The advective velocity of groundwater in the direction parallel to groundwater flow is given by:

$$\bar{v} = \frac{K}{n_e}\frac{dH}{dL}$$

Where: $\bar{v}$ = Average advective groundwater velocity (seepage velocity) [L/T]

K = Hydraulic conductivity [L/T] (19.7 ft/day)

dH/dL = Gradient [L/L] (0.0025 ft/ft)

n_e = Effective porosity (0.25).

Using this relationship in conjunction with site-specific data, the average advective groundwater velocity at the site in November 1995, was 0.20 ft/day, or approximately 71.9 feet per year (ft/yr).

3.3.2.5 Preferential Flow Paths

No preferential contaminant migration pathways were identified during the field work phase of this project. Relatively few man-made features such as utility trenches or storm sewers are present at the site; furthermore, the relatively high hydraulic conductivity of the surficial aquifer materials could limit the influence of the few potential man-made pathways. It is possible that a buried waste fuel line leading from the burn pit to an oil/water separator and then to a drainage ditch could serve as a preferential conduit for contaminated groundwater; however, this potential pathway lies

nearly parallel to the direction of groundwater flow. As a result, contaminant transport specifically associated with this potential corridor could not be discerned.

3.3.3 Groundwater Use

Groundwater in the shallow aquifer in the vicinity of the Base is not known to be used as a drinking water supply. Neighborhoods to the east and northeast of the Base obtain domestic and agricultural water primarily from private wells that tap aquifers in the deeper basalt flows. The closest residential neighborhoods are roughly 1,800 feet east (downgradient) of the site. Base drinking water is primarily supplied from a Base-owned well field 10 miles northwest of the Base. Additionally, there is a water supply well located in the southern area of the Base. This well, which also produces water from the deeper basalt aquifer, supplies roughly 10 percent of the Base's needs (HNUS, 1993b).

3.4 CLIMATE

Fairchild AFB is surrounded by semi-arid grasslands common to this area of the Columbia Basin. The Base receives approximately 16 inches of rainfall during the warm, dry summers, and 40 inches of snowfall during the cool, damp winter months. The prevailing wind direction in the region is to the northeast at an average speed of 8 miles per hour (ICF Technology, Inc., 1995). The average evapotranspiration rate for the region is reported at 12.8 inches per year (JRB Associates, 1985). Maximum infiltration rates usually occur during the early spring when snow melt runoff combines with precipitation while temperatures are still cool and evapotranspiration is low (HNUS, 1993b).

SECTION 4

NATURE AND EXTENT OF CONTAMINATION AND SOIL AND GROUNDWATER GEOCHEMISTRY

4.1 SOURCES OF CONTAMINATION

The discharge of fuel, waste fuel, and unspecified solvents during fire training exercises from before 1970 through 1991 has been identified as the primary source of soil and groundwater contamination at FT-1. Prior to 1970, fire training exercises were conducted in an unlined pit located that is no longer evident at the ground surface. The former pit was reportedly located between the recent pit and Building 1570. As no liners or other containment devices were used within the burn pit, presumably many of the unburned fuels and solvents percolated through the soil and into the groundwater following each training exercise. Between 1970 and 1991, fire training exercises were conducted at the lined pit that is still present at the site. Recent exercises consisted of floating approximately 300 gallons of uncontaminated fuel on 2 to 3 inches of water, igniting the fuel, and extinguishing it with AFFF. The solution of water, AFFF, and unburned fuel remaining in the pit after the exercise was discharged through an oil/water separator located approximately 150 feet east of the current fire training pit. The frequency of fire training exercises, the volume of fuels used for each exercise (prior to recent exercises), the start of fire training exercises at the former pit, and the dates of use of waste fuels and solvents are unknown.

4.2 SOURCE AND SOIL CHEMISTRY

Residual NAPL is defined as the NAPL that is trapped in the aquifer by the processes of cohesion and capillarity, and therefore, will not flow within the aquifer or from the aquifer matrix into a well under the influence of gravity. Mobile NAPL is defined as LNAPL that is free to flow in the aquifer and will flow from the aquifer matrix into a well under the influence of gravity. At this site, the residual NAPL consists of fuel hydrocarbons, primarily derived from jet fuel and waste solvents. The following sections describe the residual NAPL contamination found at the site. Mobile LNAPL or DNAPL was not observed in site monitoring wells and temporary monitoring points.

4.2.1 Soil BTEX Contamination

Nine soil samples and three replicate soil samples were collected from six Geoprobe® locations at FT-1 during November 1995.. The samples were analyzed for BTEX and TMBs by the USEPA NRMRL. BTEX compounds were not detected in the

three soil samples collected at ES-SB-1, ES-SB-5, or ES-MP-4S. These sampling locations are upgradient, crossgradient, and approximately 650 feet downgradient, respectively, from the lined burn pit. BTEX compounds were detected in all six soil samples and three replicate samples collected from soil boreholes ES-SB-2, ES-SB-3, and ES-SB-4. Boreholes ES-SB-2 and ES-SB-4 are located along the fringes of the burn pit (Figure 4.1). Borehole ES-SB-3 is located approximately 50 feet east-southeast (downgradient) from the burn pit. Soil samples at each of the three boreholes were collected from 4 feet and 8 to 10 feet bgs. Total BTEX concentrations in all eight of the nine samples were relatively uniform, ranging from 31.1 milligrams per kilogram (mg/kg) in the replicate 4-foot sample from borehole ES-SB-2 to 186.7 mg/kg in the replicate 8-foot sample from borehole ES-SB-4. The sample from the 4-foot interval in ES-SB-4 had a relatively low total BTEX concentration of 0.19 mg/kg. The distribution of TMB detections mirrored those for BTEX. Figure 4.1 shows the locations of soil BTEX contamination. Table 4.1 presents soil analytical data from the fall 1995 sampling.

The ROD specifies that benzene levels at FT-1 are to be remediated to less than 0.5 mg/kg. The soil sample from the 4-foot interval in ES-SB-2 had a benzene concentration of 0.568 mg/kg and was the only soil sample with a benzene concentration over 0.5 mg/kg. Benzene was detected above detection limits in 8 of the 12 soil samples, including replicates. Of the detected benzene concentrations in site soils, the percent benzene in total detected BTEX ranged from 0.1 to 1.2 percent.

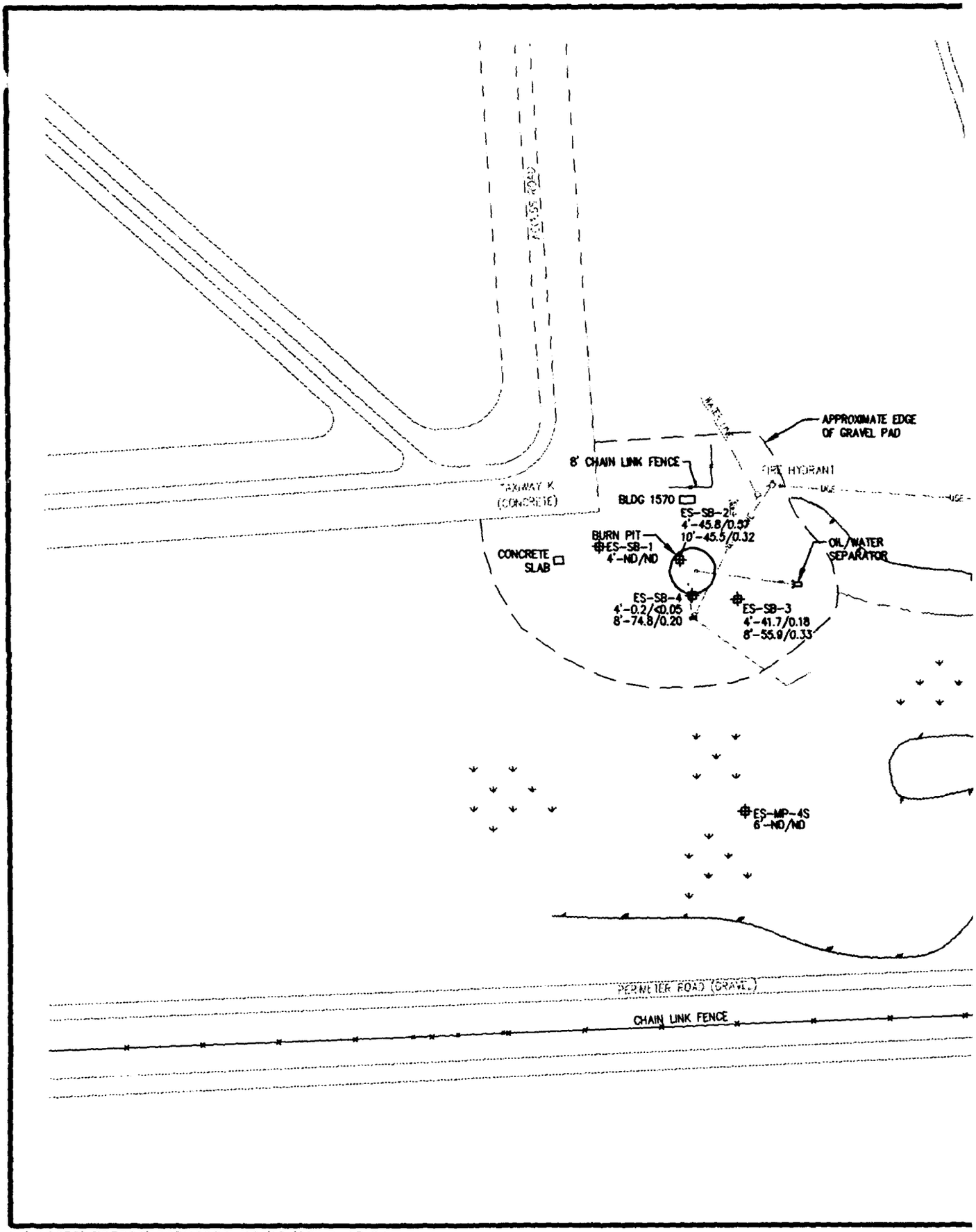
Historically, BTEX compounds also were detected in the burn pit and up to 100 feet south of the burn pit and 450 east of the burn pit along the drainage ditch leading from the oil/water separator. Historic total BTEX concentrations were comparable to or slightly higher than those observed during the present investigation. The highest detected historic concentration was 526.8 mg/kg from a depth of 5 to 6.5 feet bgs at a borehole location that was very close to borehole ES-SB-4, where the highest total BTEX concentration was detected during the current investigation at a depth of 8 feet bgs.

4.2.2 Soil Chlorinated Solvent Contamination

The 12 soil samples collected in November 1995 also were analyzed for TCE and PCE. TCE was not detected in any of soil samples; however, PCE was detected at concentrations of 0.02 to 0.07 mg/kg in five samples from boreholes ES-SB-2, ES-SB-3, ES-SB-4, and ES-SB-5. With the exception of the sample from borehole ES-SB-5 (Figure 4.1), the PCE contamination is located in the vicinity of the burn pit. Historic analytical data are not available for chlorinated solvents in site soils.

4.2.3 Total Organic Carbon

TOC concentration is an estimate of the amount of organic matter sorbed on soil particles or trapped in the interstitial passages of a soil matrix. The TOC concentration in the saturated zone is an important parameter used to estimate the amount of contaminant that could potentially be sorbed to the aquifer matrix. Sorption results in



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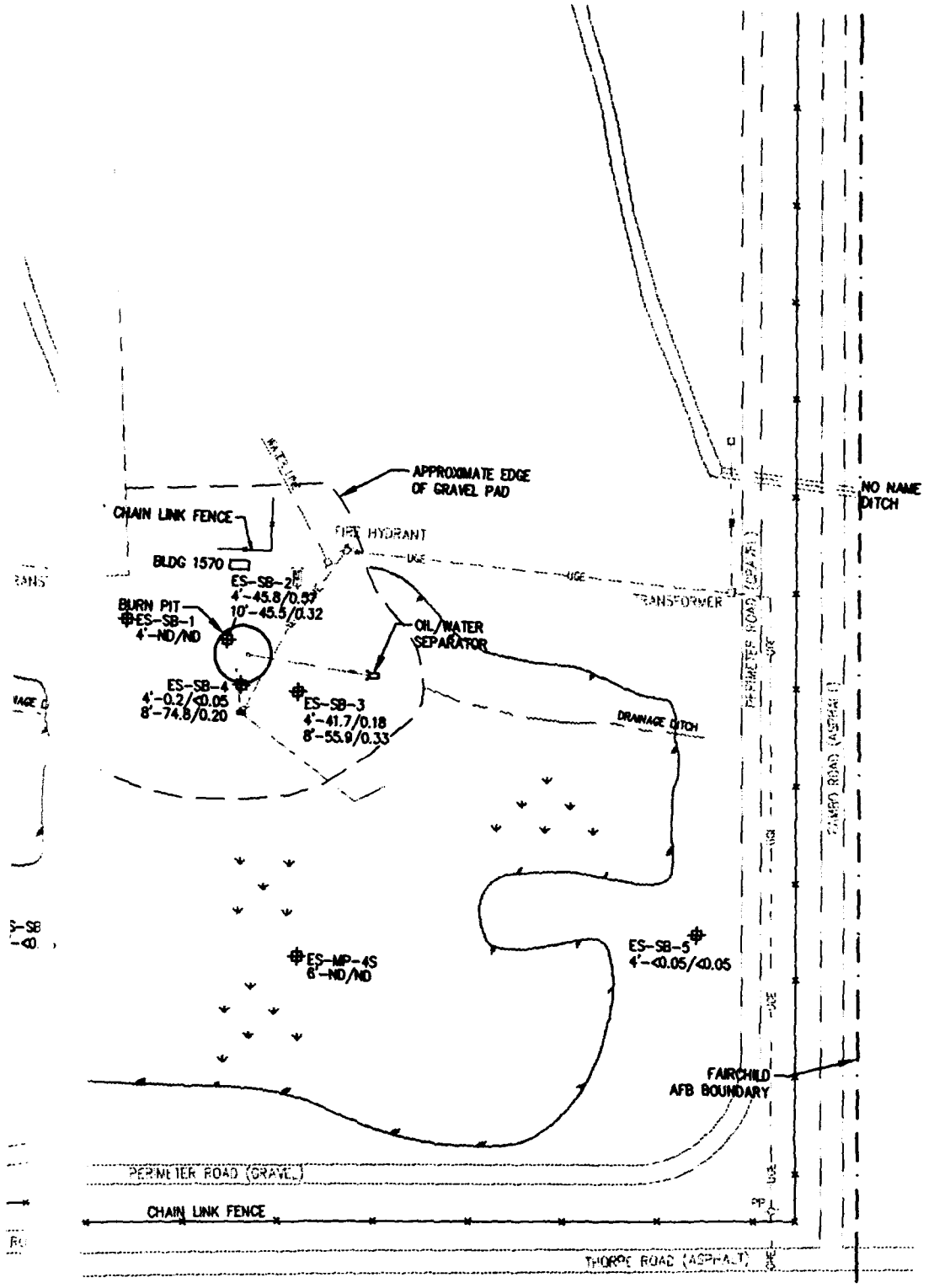


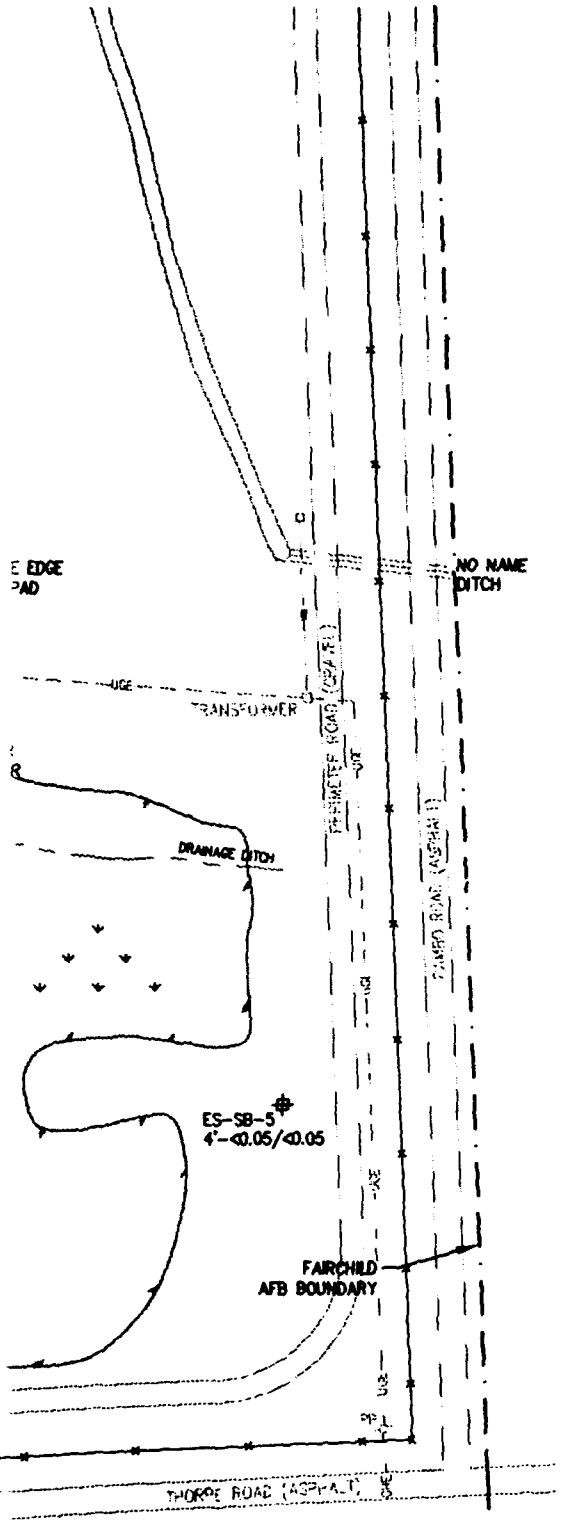
ES-SB-1
4'-ND/ND

0

BTE
(N

Remediatic
Fair

PARSON
ENGINE



LEGEND

ES-SB-1 ⊕
4'-ND/ND

SOIL SAMPLING LOCATION WITH SAMPLED DEPTH (FEET) AND SOIL BTEX/BENZENE CONCENTRATION (mg/kg)

N

0 100 200 400

FEET

FIGURE 4.1

BTEX/BENZENE IN SOIL (NOVEMBER 1995)

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 4.1
1995 SOIL ANALYTICAL DATA
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Sample Identification	Depth (feet bgs)	Benzene (mg/kg)[a]	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Total Xylenes (mg/kg)	Total BTEX (mg/kg)	TCE (mg/kg)	Tetrachloroethene (mg/kg)	Total TMB (mg/kg)	TOC (%)
ES-SB-1-4	4	ND[b]	ND	ND	ND	ND	ND	ND	ND	0.29
ES-SB-2-4	4	0.57	5.08	1.20	39.0	45.8	ND	ND	36.5	1.08
ES-SB-2-4D[c]	4	0.27	3.44	1.09	26.3	31.1	ND	ND	26.6	1.09
ES-SB-2-10	10	0.32	1.49	5.24	38.4	45.5	ND	0.03	67.6	0.16
ES-SB-3-4	4	0.18	1.04	1.82	38.7	41.7	ND	0.07	51.6	2.61
ES-SB-3-8	8	0.33	0.20	0.19	55.2	55.9	ND	0.07	68.6	1.52
ES-SB-3-8D	8	0.26	0.17	0.28	51.5	52.2	ND	0.05	65.8	1.76
ES-SB-4-4	4	<0.05	ND	<0.05	0.19	0.19	ND	ND	0.46	0.87
ES-SB-4-8	8	0.21	1.45	0.06	73.1	74.8	ND	0.07	94.4	0.85
ES-SB-4-8D	8	0.24	2.53	0.05	184	187	ND	0.05	232	0.77
ES-SB-5-4	4	<0.05	<0.05	<0.05	<0.05	<0.05	ND	0.02	<0.05	0.48
ES-MP-4S-6	6	ND	ND	ND	ND	ND	ND	ND	ND	0.03

[a] mg/kg = milligrams per kilogram.
[b] ND = Not detected.
[c] D = replicate of preceding sample.

retardation of the contaminant plume migration relative to the average advective groundwater velocity.

All of the soil samples collected by Parsons ES were analyzed by the USEPA NRMRL for TOC. The samples that were taken at or near the groundwater interface were used to estimate contaminant retardation as a result of sorption. TOC results range from 0.03 to 2.61 percent (Table 4.1). TOC analyses often are influenced by the presence of soil contamination, which may cause high soil TOC concentrations without necessarily reflecting an increase in the sorptive properties of the soil. The average TOC concentration for the samples containing no detected BTEX and collected near the water table is 0.42 percent.

4.3 OVERVIEW OF BTEX AND CAH BIODEGRADATION

Mechanisms for natural attenuation of CAHs and BTEX include biodegradation, dispersion, dilution from recharge, sorption, and volatilization. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. Intrinsic bioremediation occurs when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. In order to provide a foundation for interpreting site data, the following sections present the major bioremediation processes that act upon CAHs and BTEX. Furthermore, biodegradation of either BTEX or CAHs can play a significant role in the biodegradation of the other.

4.3.1 Biodegradation of BTEX

Fuel hydrocarbons biodegrade naturally when an indigenous population of hydrocarbon-degrading microorganisms is present in the aquifer and sufficient concentrations of electron acceptors and nutrients are available to these organisms. In most subsurface environments, both aerobic and anaerobic degradation of fuel hydrocarbons can occur, often simultaneously in different parts of the plume.

Microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous reduction/oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Fuel hydrocarbons occupy the role of electron donor for microbial metabolism and are completely degraded or detoxified (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states. Common native electron acceptors include DO, nitrate, ferric iron, sulfate, and carbon dioxide.

The driving force of BTEX degradation is electron transfer and is quantified by the Gibbs free energy of the reaction ($\Delta G°_r$) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of $\Delta G°_r$ represents the quantity of free energy consumed or yielded to the system during the reaction. Table 4.2 lists stoichiometry of the redox equations involving BTEX and the resulting $\Delta G°_r$. Although thermodynamically favorable, most of the reactions involved in BTEX oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the

TABLE 4.2
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Coupled Benzene Oxidation Reactions	$\Delta G°_r$ (kcal/mole Benzene)	$\Delta G°_r$ (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5O_2 + C_6H_6 \Rightarrow 6CO_{2,g} + 3H_2O$ *Benzene oxidation /aerobic respiration*	-765.34	-3202	3.07:1
$6NO_3^- + 6H^+ + C_6H_6 \Rightarrow 6CO_{2,g} + 6H_2O + 3N_{2,g}$ *Benzene oxidation / denitrification*	-775.75	-3245	4.77:1
$3.75\ NO_3^- + C_6H_6 + 7.5\ H^+ + 0.75\ H_2O \Rightarrow 6\ CO_2 + 3.75\ NH_4^+$ *Benzene oxidation / nitrate reduction*	-524.1	-2193	2.98:1
$60H^+ + 30\underline{Fe(OH)_{3,a}} + C_6H_6 \Rightarrow 6CO_2 + 30Fe^{2+} + 78H_2O$ *Benzene oxidation / iron reduction*	-560.10	-2343	21.5:1 [a]
$7.5H^+ + 3.75SO_4^{2-} + C_6H_6 \Rightarrow 6CO_{2,g} + 3.75H_2S° + 3H_2O$ *Benzene oxidation / sulfate reduction*	-122.93	-514.3	4.61:1
$4.5H_2O + C_6H_6 \Rightarrow 2.25CO_{2,g} + 3.75CH_4$ *Benzene oxidation / methanogenesis*	-32.40	-135.6	0.77:1 [b]

Coupled Toluene Oxidation Reactions	$\Delta G°_r$ (kcal/mole Toluene)	$\Delta G°_r$ (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9O_2 + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4H_2O$ *Toluene oxidation /aerobic respiration*	-913.76	-3823	3.13:1
$7.2NO_3^- + 7.2H^+ + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 7.6H_2O + 3.6N_{2,g}$ *Toluene oxidation / denitrification*	-926.31	-3875	4.85:1
$72H^+ + 36\underline{Fe(OH)_{3,a}} + C_6H_5CH_3 \Rightarrow 7CO_2 + 36Fe^{2+} + 94H_2O$ *Toluene oxidation / iron reduction*	-667.21	-2792	21.86:1 [a]
$9H^+ + 4.5SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7CO_{2,g} + 4.5H_2S° + 4H_2O$ *Toluene oxidation / sulfate reduction*	-142.86	-597.7	4.7:1
$5H_2O + C_6H_5CH_3 \Rightarrow 2.5CO_{2,g} + 4.5CH_4$ *Toluene oxidation / methanogenesis*	-34.08	-142.6	0.78:1 [b]

TABLE 4.2 (CONCLUDED)
COUPLED OXIDATION REACTIONS FOR BTEX COMPOUNDS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Coupled Ethylbenzene Oxidation reactions	$\Delta G°_r$ (kcal/mole Ethyl-benzene)	$\Delta G°_r$ (kJ/mole Ethyl-benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5O_2 + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5H_2O$ *Ethylbenzene oxidation /aerobic respiration*	-1066.13	-4461	3.17:1
$8.4NO_3^- + 8.4H^+ + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *Ethylbenzene oxidation / denitrification*	-1080.76	-4522	4.92:1
$84H^+ + 42Fe(OH)_{3,a} + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *Ethylbenzene oxidation / iron reduction*	-778.48	-3257	22:1 [a/]
$10.5H^+ + 5.25SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5.25H_2S^o + 5H_2O$ Eth *ylbenzene oxidation / sulfate reduction*	-166.75	-697.7	4.75:1
$5.5H_2O + C_6H_5C_2H_5 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *Ethylbenzene oxidation / methanogenesis*	-39.83	-166.7	0.79:1 [b/]

Coupled m-Xylene Oxidation Reactions	$\Delta G°_r$ (kcal/mole *m*-xylene)	$\Delta G°_r$ (kJ/mole *m*-xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5O_2 + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5H_2O$ *m-Xylene oxidation /aerobic respiration*	-1063.25	-4448	3.17:1
$8.4NO_3^- + 8.4H^+ + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *m-Xylene oxidation / denitrification*	-1077.81	-4509	4.92:1
$84H^+ + 42Fe(OH)_{3,a} + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *m-Xylene oxidation / iron reduction*	-775.61	-3245	22:1 [a/]
$10.5H^+ + 5.25SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5.25H_2S^o + 5H_2O$ *m-Xylene oxidation / sulfate reduction*	-163.87	-685.6	4.75:1
$5.5H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *m-Xylene oxidation / methanogenesis*	-36.95	-154.6	0.79:1 [b/]

[a/] Mass of ferrous iron produced during microbial respiration.
[b/] Mass of methane produced during microbial respiration.

necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy (i.e. $\Delta G°_r < 0$). Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms typically use electron acceptors (as available) in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon dioxide.

In addition to being controlled by the energy yield of the reaction, the expected sequence of redox processes is also a function of the oxidizing potential of the groundwater. This potential is a measure of the relative tendency of a solution or chemical reaction to accept or transfer electrons. As each subsequent electron acceptor is utilized, the groundwater becomes more reducing and the redox potential of the water decreases. The main force driving this change in redox potential is microbially mediated redox reactions. Redox potential can be used as an indicator of which redox reactions may be operating at a site.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, ferric iron, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation of fuel hydrocarbons and CAHs can occur by denitrification, ferric iron reduction, sulfate reduction, methanogenesis. Other, less common anaerobic degradation mechanisms such as reductive dehalogenation or manganese or nitrate reduction may dominate if the physical and chemical conditions in the subsurface favor use of these electron acceptors. Anaerobic destruction of BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990). Environmental conditions and microbial competition will ultimately determine which processes will dominate. Vroblesky and Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination.

4.3.2 Biodegradation of Chlorinated Solvents

Whereas BTEX is biodegraded in essentially one step by acting as an electron donor/carbon source, CAHs may undergo several types of biodegradation involving several steps. CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although the use of CAHs as electron acceptors appears to be the most likely.

In a pristine aquifer, native organic carbon is utilized as an electron donor and DO is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or low-molecular-weight CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH

biodegradation is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds also will provide evidence on the types of biodegradation processes acting at a site.

As with BTEX, the driving force behind redox reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy (i.e. $\Delta G°_r < 0$).

4.3.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. Figure 4.2 illustrates the transformation of chlorinated ethenes via reductive dehalogenation. In general, reductive dehalogenation occurs by sequential dehalogenation from TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. Of these compounds, TCE is more susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in TCE plumes that are undergoing reductive dehalogenation.

In addition to being affected by the degree of chlorination of the CAH, reductive dehalogenation also can be controlled by the redox conditions of the site groundwater system. In general, reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994). Dehalogenation of TCE to DCE can proceed under mildly reducing conditions such as nitrate reduction or iron (III) reduction (Vogel *et al.*, 1987), while the transformation of DCE to VC, or the transformation from VC to ethene requires more

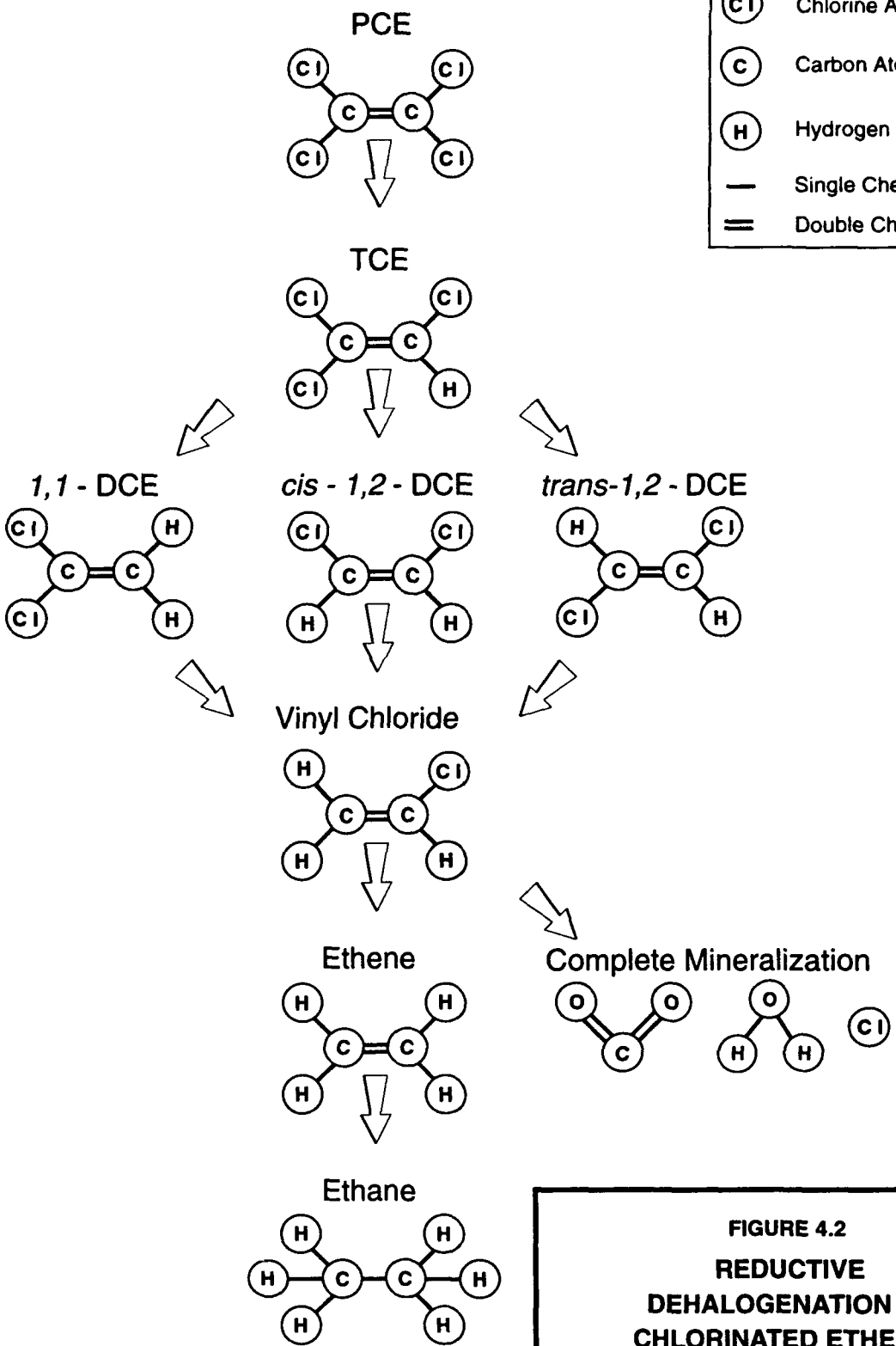


FIGURE 4.2

REDUCTIVE DEHALOGENATION OF CHLORINATED ETHENES

Site FT-1
Remediation by Natural Attenuation
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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strongly reducing conditions (Freedman and Gossett, 1989; DeStefano *et al.*, 1991; DeBruin *et al.*, 1992).

Because CAH compounds are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, or fuel hydrocarbons.

4.3.2.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs (e.g., VC, DCE, or chlorobenzene) may be utilized as electron donors in biologically mediated redox reactions.

For example, while Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE, other less chlorinated CAHs have been shown to be used as substrates. Davis and Carpenter (1990) describe the aerobic oxidation of VC in groundwater. McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. Klier *et al.* (1996) describe aerobic mineralization of all three isomers of DCE. In addition, Bradley and Chapelle (1996) show evidence of oxidation of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Aerobic metabolism of VC may be characterized by a loss of VC mass, a decreasing molar ratio of VC to other CAH compounds, and the presence of chloromethane.

4.3.2.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of dehalogenation decreases.

In the cometabolic process, TCE is indirectly transformed by bacteria as they use BTEX or another substrate to meet their energy requirements. Therefore, TCE does not enhance the degradation of BTEX or other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (BTEX or other organic carbon sources) limit cometabolism of CAHs.

4.4 GROUNDWATER CHEMISTRY

Three lines of evidence can be used to document the occurrence of natural attenuation: 1) geochemical evidence; 2) documented loss of contaminant mass at the field scale; and 3) laboratory microcosm studies. The first two lines of evidence (geochemical evidence and documented loss of contaminants) are used herein to support the occurrence of RNA, as described in the following sections. Because these two lines of evidence strongly suggest that natural attenuation of benzene (and other organic compounds) is occurring at this site, laboratory microcosm studies were not deemed necessary.

4.4.1 Dissolved Hydrocarbon and Chlorinated Solvent Contamination

Groundwater samples collected at FT-1 were analyzed for BTEX compounds, TPH, and chlorinated solvent concentrations on at least eight occasions since 1986. The highest detected total BTEX concentrations have historically been detected in monitoring wells MW-3 and MW-152. Both wells are screened in the shallow unconsolidated deposits and are located approximately 200 to 300 feet downgradient from the existing burn pit at FT-1. The detected concentrations have fluctuated through time, possibly as a result of sampling techniques, laboratory analyses, or seasonal variations; however, since 1989, total detected BTEX concentrations have always exceeded 200 µg/L at both wells, with benzene concentrations greater than 50 µg/L. Monitoring well MW-156 is located within 100 feet of the existing burn pit; however, BTEX contamination has never been detected in groundwater from this well because it is both crossgradient from the existing burn pit and is screened in the shallow bedrock (beneath the unconsolidated deposits). The highest total BTEX concentration detected in a shallow bedrock well at site FT-1 was 49.1 µg/L, with no contribution from benzene.

The highest dissolved chlorinated solvent concentrations have consistently been detected in monitoring well MW-2, with maximum detected concentrations for TCE and *cis*-1,2-DCE of 29 and 360 µg/L, respectively. Monitoring well MW-2 is located approximately 200 feet north (crossgradient) from the existing burn pit. Elsewhere at the site TCE concentrations have not exceeded 6 µg/L and DCE concentrations have not exceeded 17 µg/L. TCE has not been detected in samples collected from monitoring wells MW-3 and MW-152, the downgradient wells nearest to the existing burn pit; however, beginning with 1995 sampling events, vinyl chloride has consistently been detected in both of these downgradient wells at concentrations in excess of 10 µg/L.

Analytical results for groundwater samples collected in November 1995 at previously installed monitoring wells confirm these historical observations. Analytical results for samples from temporary monitoring points were used to better define the vertical extent of contamination. Tables 4.3 and 4.4 summarize groundwater contaminant data for the November 1995 samples. Analytical results from the current investigation are discussed in the following subsections.

4.4.1.1 Dissolved BTEX Contamination

The estimated areal distribution of total dissolved BTEX in groundwater for November 1995, with supplemental data for ES-GPC from May 1996, is presented on Figure 4.3. The area includes both wells with total dissolved BTEX concentrations detected in November 1995 (MW-3 and MW-151) and extends approximately 500 feet east southeast from the existing burn pit to within a few feet of monitoring wells MW-155 and MW-227. These wells are thought to be near the leading edge of the dissolved BTEX plume because benzene and o-xylene were identified below the detection level of 1 µg/L in the groundwater sample from MW-227 during November 1995, and because BTEX compounds were detected in a groundwater sample collected from MW-155 during May 1995 (ES&T and MWA, 1995). In May 1996, a groundwater grab sample from near the center of the burn pit had a benzene concentration of 229 µg/L and total BTEX concentration of 5,220 µg/L. In November 1995, the maximum observed total BTEX concentration was 1,870 µg/L, in the sample collected from shallow monitoring well MW-152. The maximum benzene concentration of 251 µg/L also was detected at this location. The only other BTEX detected was in the sample from MW-3 at 1,040 µg/L, with benzene accounting for 174 µg/L. With detections of BTEX compounds (*including benzene*) from only three of the sampled locations at FT-1 in November 1995, an isopleth map could not be constructed.

In November 1995, dissolved BTEX concentrations were not detected from any well screened below the unconsolidated deposits, suggesting that BTEX contamination is not migrating vertically downward into the shallow bedrock. In addition, the vertical distribution of BTEX in the unconsolidated deposits was evaluated at the ES-GP-1D/MW-3 cluster. The sample from monitoring well MW-3, screened across the water table, had a total BTEX concentration of 1,040 µg/L; whereas, BTEX was not detected in the sample from monitoring point ES-GP-1D, screened at the base of the unconsolidated deposits. This suggests that the vertical migration of BTEX within the unconsolidated deposits at the head of the plume also is insignificant.

TABLE 4.3

GROUNDWATER QUALITY DATA SUMMARY FOR BTEX, TMBs, AND FUEL CARBON

SITE FT-1

REMEDIATION BY NATURAL ATTENUATION TS

FAIRCHILD AFB, WASHINGTON

Sample ID	Date Sampled	Benzene (µg/L)[a]	Toluene (µg/L)	Ethyl-Benzene (µg/L)	p-Xylenes (µg/L)	m-Xylenes (µg/L)	o-Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	Fuel Carbon (µg/L)
ES-GP1	11/7/95	BLQ[b]	ND[c]	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
ES-GP2	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ES-GP2dup	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ES-GP3	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ES-GP4	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ES-GPC	5/30/96	229	273	616	968	2823	312	5221	282	799	434	8298
MW-1	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-2	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-3	11/7/95	174	4.8	198	184	465	8.8	1035	97	274	151	1760
MW-4	11/6/95	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	ND	BLQ
MW-49	11/6/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-50	11/6/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-52	11/8/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-53	11/8/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-59	11/6/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-61	11/8/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-61dup	11/8/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-100	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-151	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-153	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-152	11/8/95	251	12.9	321	364	893	27.8	1870	158	437	217	2900
MW-154	11/7/95	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
MW-155	11/6/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-156	11/6/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-225	11/6/95	BLQ	ND	ND	ND	ND	BLQ	BLQ	ND	ND	ND	BLQ
MW-226	11/6/95	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-227	11/6/95	BLQ	ND	ND	ND	ND	BLQ	BLQ	ND	ND	ND	BLQ

[a] µg/L = micrograms per liter.
[b] BLQ = below level of quantitation.
[c] ND = not detected.

TABLE 4.4

GROUNDWATER QUALITY DATA SUMMARY FOR CHLORINATED VOLATILE ORGANIC COMPOUNDS

SITE FT-1

REMEDIATION BY NATURAL ATTENUATION TS

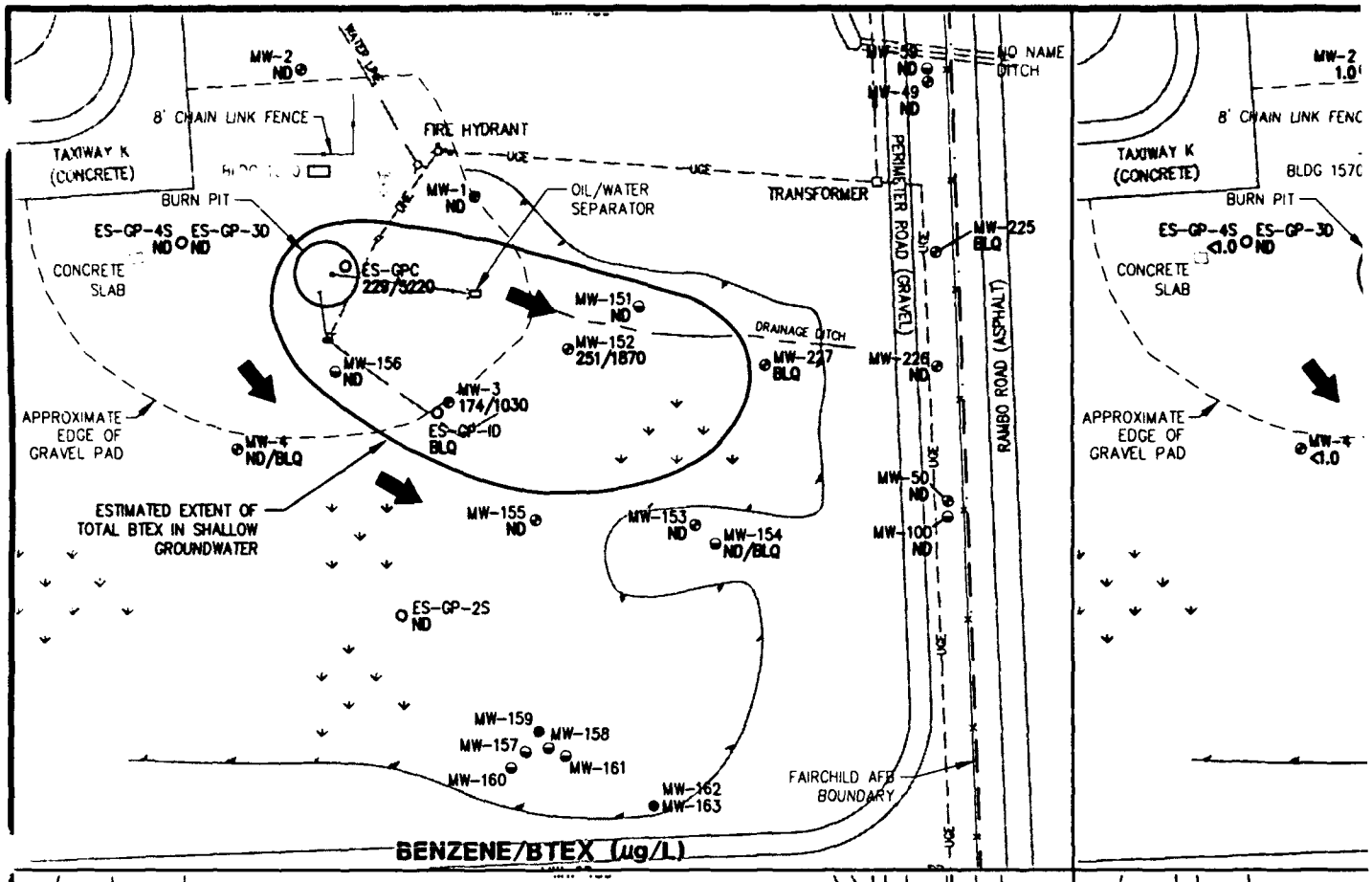
FAIRCHILD AFB, WASHINGTON

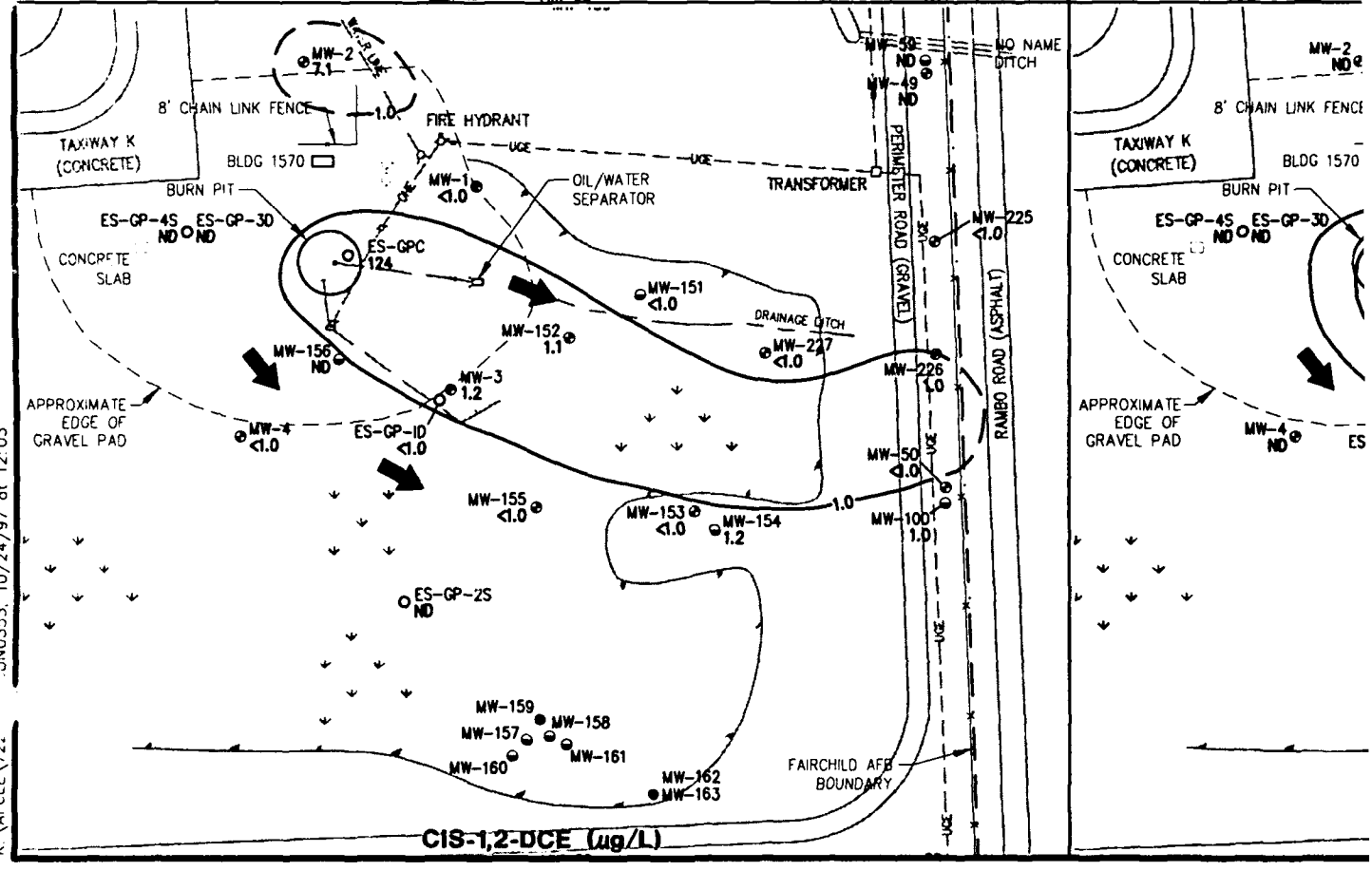
Sample Identification	Date Sampled	PCE (µg/L)[a]	TCE (µg/L)	1,1-DCE (µg/L)	Trans-1,2-DCE (µg/L)	Cis-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)	Ethene (mg/L)	Ethane (mg/L)
ES-GPC	5/30/96	ND	63.4	<1.0	ND	124	11.9	NA	NA
ES-GP1	11/7/95	ND[b]	ND	ND	ND	<1.0	2.4	<0.003	ND
ES-GP2	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND
ES-GP3	11/7/95	ND	ND	ND	ND	ND	ND	ND	ND
ES-GP4	11/7/95	ND	<1.0	ND	ND	ND	ND	ND	ND
MW-1	11/7/95	ND	<1.0	ND	ND	<1.0	ND	ND	ND
MW-2	11/7/95	ND	1.0	ND	3.2	7.1	ND	ND	ND
MW-3	11/7/95	ND	ND	ND	ND	1.2	37.9	0.017	ND
MW-3D	11/7/95	ND	ND	ND	ND	1.0	35.3	NA[c]	NA
MW-4	11/6/95	ND	<1.0	ND	ND	<1.0	ND	ND	ND
MW-49	11/6/95	ND	ND	ND	ND	ND	ND	ND	ND
MW-50	11/6/95	ND	1.3	ND	ND	<1.0	ND	ND	ND
MW-50D	11/6/95	ND	1.1	ND	ND	<1.0	ND	ND	ND
MW-52	11/8/95	ND	ND	ND	ND	ND	ND	ND	ND
MW-53	11/8/95	ND	<1.0	ND	ND	ND	ND	ND	ND
MW-59	11/6/95	ND	ND	ND	ND	ND	ND	ND	ND
MW-61	11/8/95	ND	ND	ND	ND	ND	ND	ND	ND
MW-100	11/7/95	ND	<1.0	<1.0	ND	1.0	2.2	ND	<0.002
MW-151	11/7/95	ND	ND	ND	ND	<1.0	ND	ND	ND
MW-152	11/8/95	ND	ND	ND	ND	1.1	26.7	<0.003	ND
MW-152D	11/8/95	ND	ND	ND	ND	1.0	25.8	<0.003	ND
MW-153	11/7/95	ND	<1.0	ND	ND	<1.0	ND	ND	ND
MW-154	11/7/95	ND	<1.0	ND	ND	1.2	ND	ND	ND
MW-155	11/6/95	ND	<1.0	ND	ND	<1.0	ND	ND	ND
MW-155D	11/6/95	ND	<1.0	ND	ND	<1.0	ND	ND	ND
MW-156	11/6/95	ND	ND	ND	ND	ND	ND	ND	ND
MW-225	11/6/95	ND	ND	ND	ND	<1.0	ND	ND	ND
MW-225D	11/6/95	ND	ND	ND	ND	<1.0	ND	ND	ND
MW-226	11/6/95	ND	ND	ND	ND	1.0	ND	ND	ND
MW-227	11/6/95	ND	ND	ND	ND	<1.0	4.0	ND	ND

[a] µg/L = micrograms per liter.

[b] ND = Not detected.

[c] NA = Not Available.





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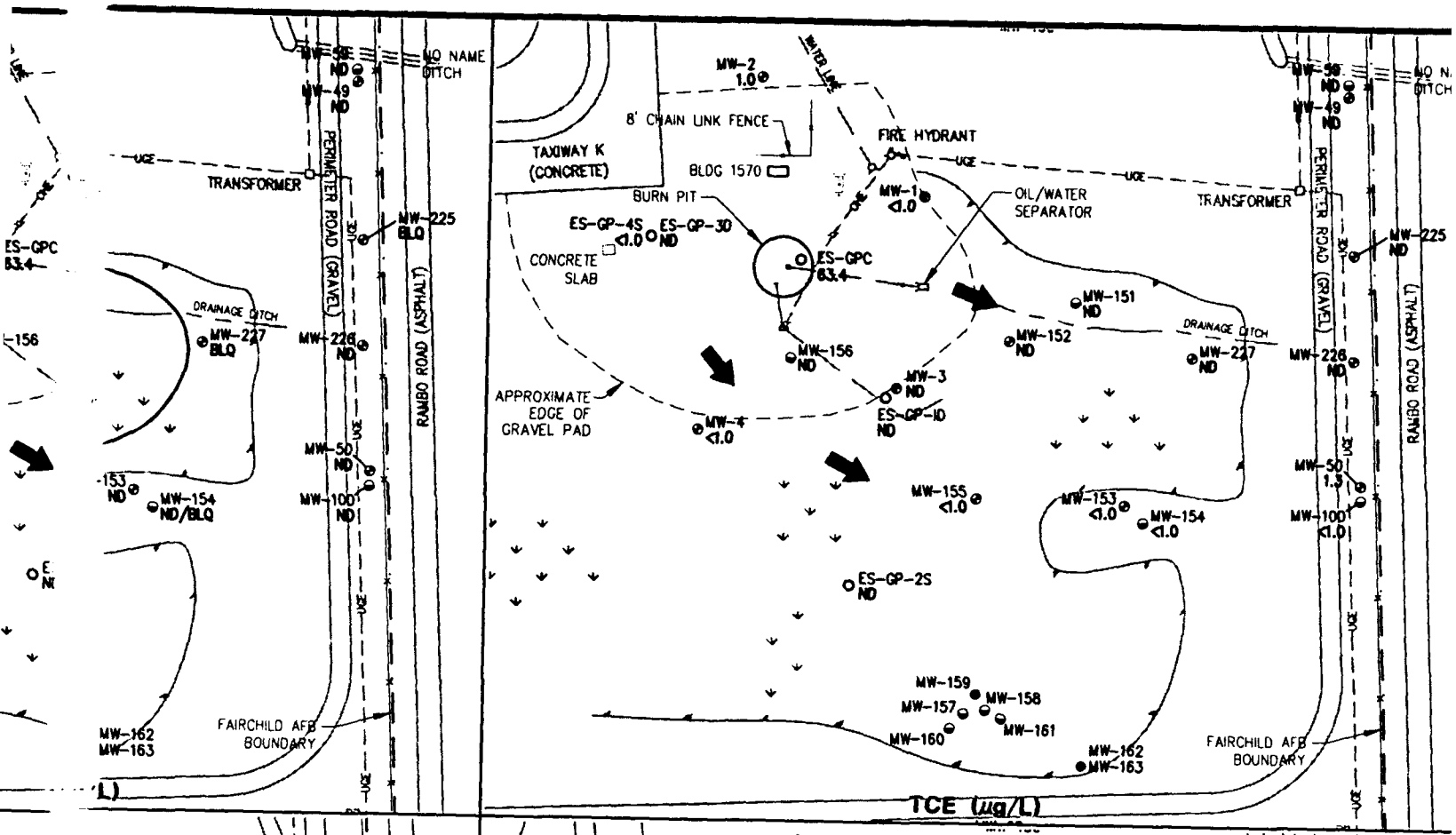
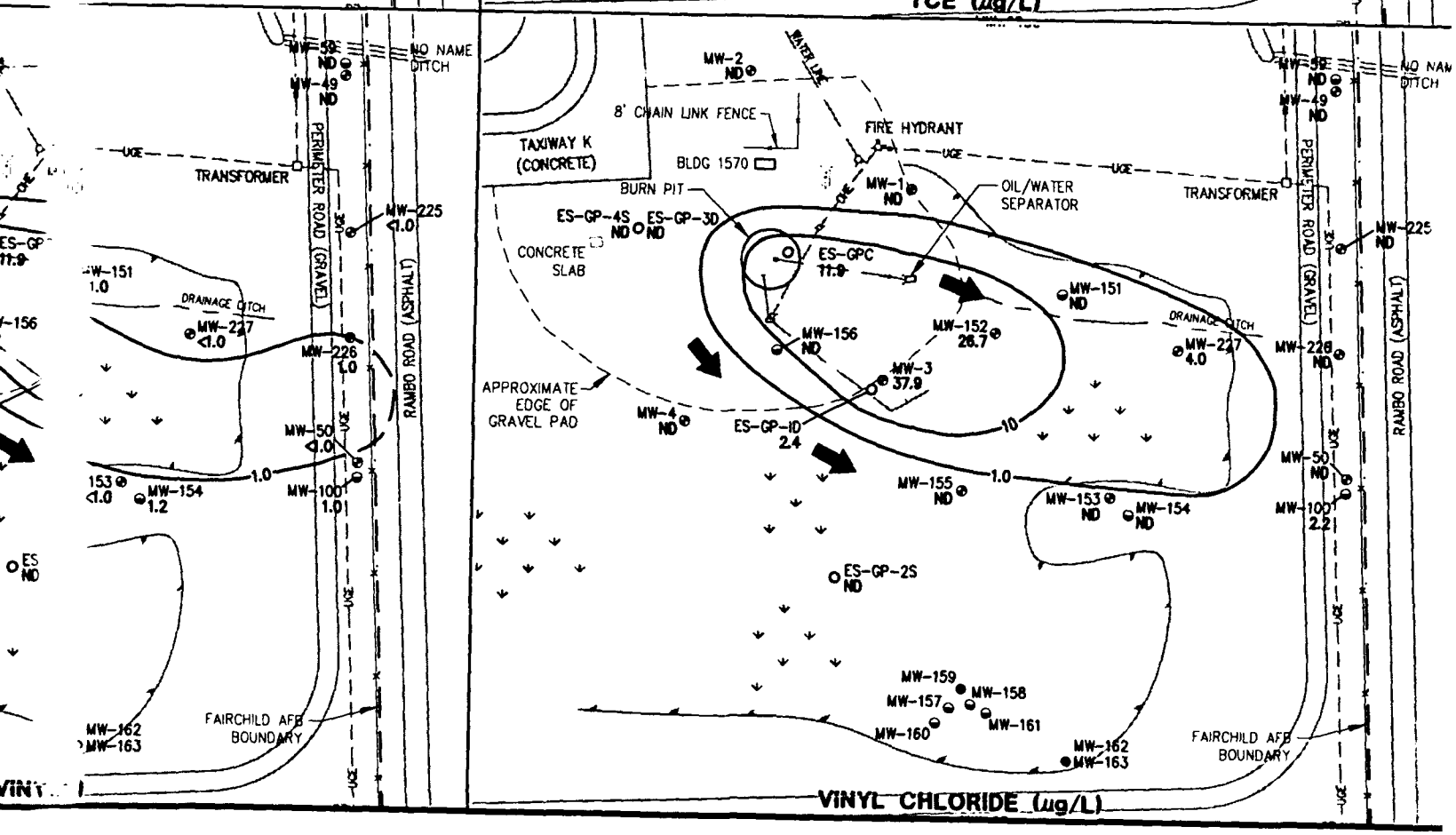
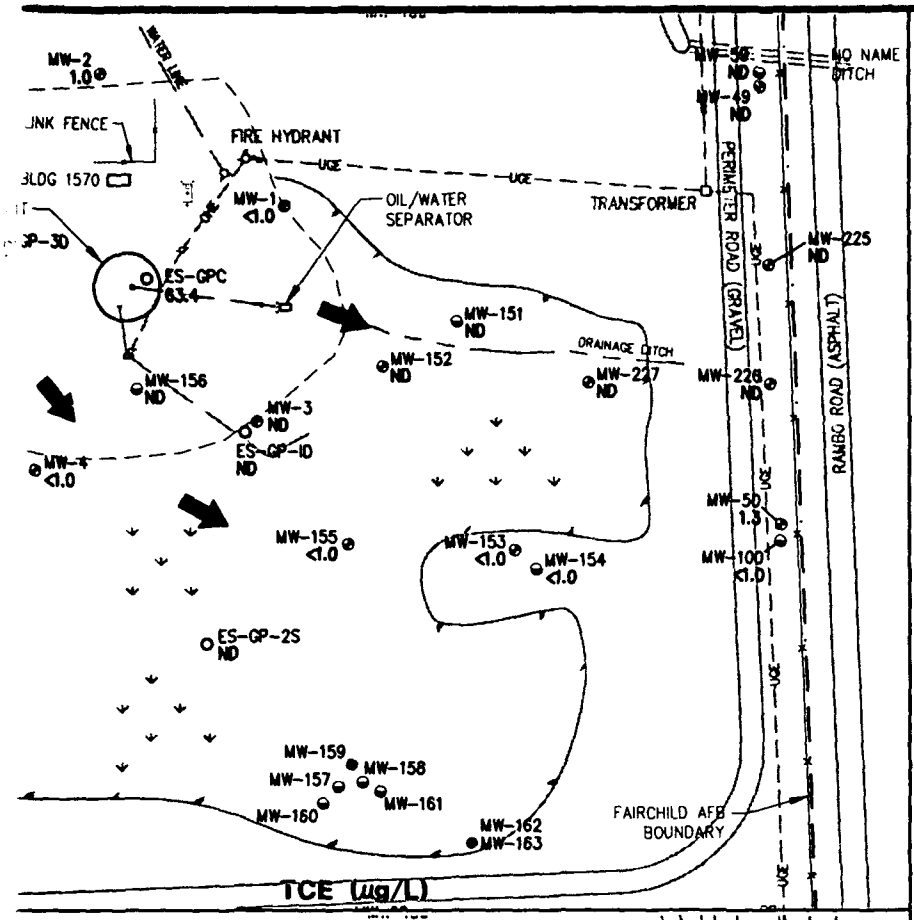
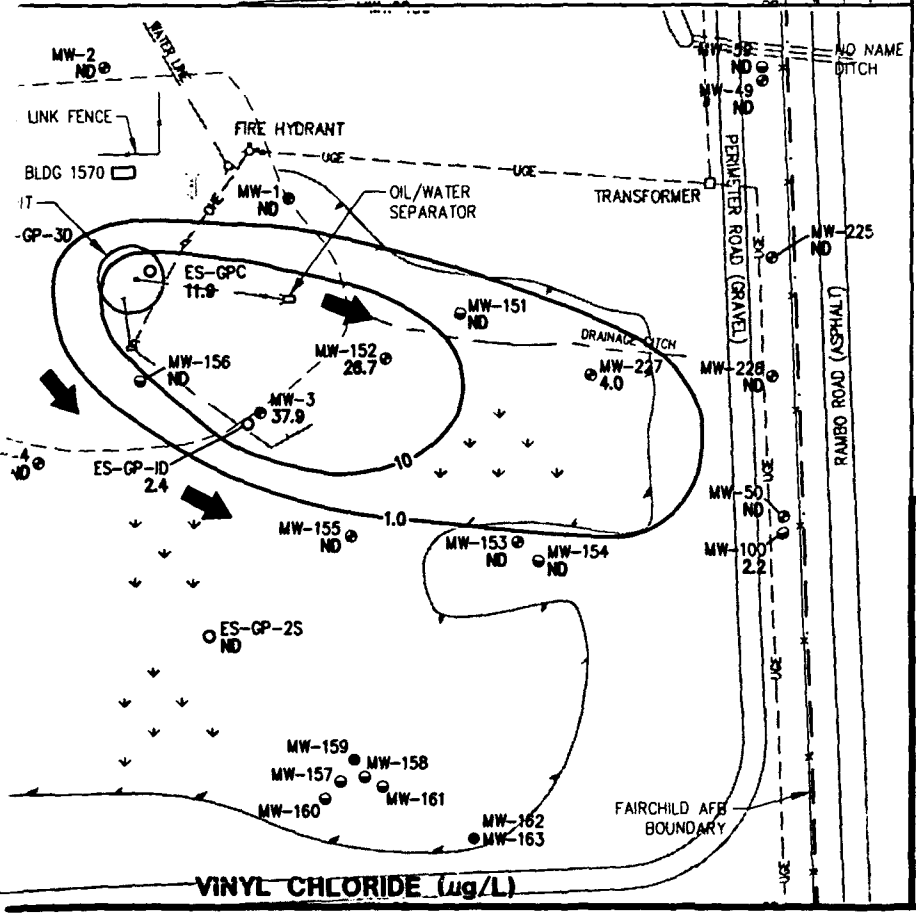

NO NAME DITCH
PERIMETER ROAD (GRAVEL)
RAMBO ROAD (ASPHALT)
TRANSFORMER
DRAINAGE DITCH
MW-225 BLQ
MW-227 BLQ
MW-226 ND
MW-50 ND
MW-100 ND
MW-154 ND/BLQ
MW-162
MW-163
FAIRCHILD AFB BOUNDARY
MW-2 1.0
8' CHAIN LINK FENCE
TAXIWAY K (CONCRETE)
BLDG 1570
FIRE HYDRANT
MW-1 <1.0
BURN PIT
ES-GP-4S <1.0
ES-GP-3D ND
OIL/WATER SEPARATOR
CONCRETE SLAB
ES-GPC 63.4
MW-151 ND
MW-152 ND
MW-156 ND
MW-3 ND
ES-GP-1D ND
APPROXIMATE EDGE OF GRAVEL PAD
MW-4 <1.0
MW-155 <1.0
MW-153 <1.0
MW-154 <1.0
ES-GP-2S ND
MW-159
MW-158
MW-157
MW-161
MW-160
MW-50 1.3
MW-100 <1.0
TCE (µg/L)


NO NAME DITCH
PERIMETER ROAD (GRAVEL)
RAMBO ROAD (ASPHALT)
TRANSFORMER
DRAINAGE DITCH
MW-225 <1.0
MW-227 <1.0
MW-226 1.0
MW-50 <1.0
MW-100 1.0
MW-154 1.2
MW-162
MW-163
FAIRCHILD AFB BOUNDARY
MW-2 ND
8' CHAIN LINK FENCE
TAXIWAY K (CONCRETE)
BLDG 1570
FIRE HYDRANT
MW-1 ND
BURN PIT
ES-GP-4S ND
ES-GP-3D ND
OIL/WATER SEPARATOR
CONCRETE SLAB
ES-GPC 11.9
MW-151 ND
MW-152 26.7
MW-156 ND
MW-3 37.9
MW-4 ND
ES-GP-1D 2.4
APPROXIMATE EDGE OF GRAVEL PAD
MW-155 ND
MW-153 ND
MW-154 ND
ES-GP-2S ND
MW-159
MW-158
MW-157
MW-161
MW-160
MW-225 ND
MW-227 4.0
MW-50 ND
MW-100 2.2
VINYL CHLORIDE (µg/L)





LEGEND

1.0⊕	SHALLOW MONITORING WELL WITH ANALYTE CONCENTRATION
<1.0⊕	SHALLOW BEDROCK MONITORING WELL WITH ANALYTE CONCENTRATION
•	DEEP BEDROCK MONITORING WELL WITH ANALYTE CONCENTRATION
ND○	TEMPORARY MONITORING POINT
ND	NOT DETECTED
BLQ	BELOW LEVEL OF QUANTITATION
—1—	LINE OF EQUAL ANALYTE CONCENTRATION (µg/L) (DASHED WHERE INFERRED)
⬅	APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTE:
CONTOURED ON THE BASIS OF ANALYTE CONCENTRATIONS MEASURED AT SHALLOW MONITORING WELLS AND POINTS.

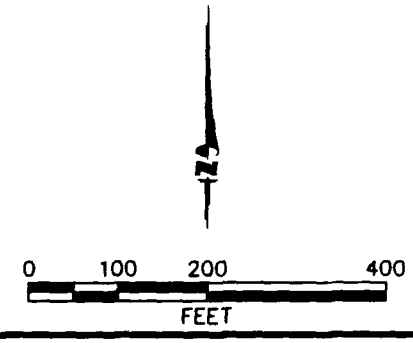


FIGURE 4.3

BTEX AND CHLORINATED SOLVENT CONCENTRATIONS IN SHALLOW GROUNDWATER

Site FT-1
Remediation By Natural Attenuation TS
Fairchild Air Force Base, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

4.4.1.2 Dissolved Chlorinated Solvent Contamination

The distributions of dissolved TCE, *cis*-1,2-DCE, and vinyl chloride in groundwater for November 1995 (with May 1996 data for ES-GPC) are presented on Figure 4.3. The reported concentrations of individual chlorinated solvents, ethene, and ethane are presented in Table 4.2. The sources of chlorinated solvents within the study area is unclear. Given that chlorinated solvents were at one time used in fire training activities, presumably at least some of the site dissolved chlorinated solvent contamination originates from the area of former fire training activities.

Vinyl chloride and *cis*-1,2-DCE plumes were estimated to extend from the existing burn pit to the vicinity of Perimeter Road, approximately 650 feet downgradient from the burn pit. Isopleths are drawn on the basis of concentrations detected in samples from sampling locations screened in the unconsolidated deposits. In the unconsolidated deposits, TCE distribution could not be contoured because the three TCE detections (at ES-GPC, MW-2, and MW-50) were widely separated spatially (Figure 4.3). The highest concentrations of both TCE and DCE were detected in the May 1996 groundwater sample from the burn pit at 63.4 µg/L and 124 µg/L, respectively. Consistent with historic sampling results, one of the two TCE detections outside of the burn pit and the highest *cis*-1,2-DCE detection (7.1 µg/L) outside of the burn pit were measured in the sample collected from crossgradient monitoring well MW-2, located approximately 200 feet north from the existing burn pit.

Of all detected downgradient chlorinated solvents from the burn pit, vinyl chloride was detected at the highest concentrations. Vinyl chloride concentrations of 38 µg/L and 27 µg/L were detected in samples from monitoring wells MW-3 and MW-152, respectively. These two locations are directly downgradient from the existing burn pit and are the same two downgradient locations where BTEX was detected (Figure 4.3). A vinyl chloride concentration of 11.9 µg/L was detected in the May 1996 groundwater sample from ES-GPC in the burn pit.

As with dissolved BTEX, vertical migration for dissolved chlorinated solvents appears to be insignificant. For instance, at the MW-3/ES-GP-1D well cluster vinyl chloride was detected at 2.4 µg/L immediately above the bedrock (ES-GP-1D) and at 38 µg/L near the water table (MW-3). The only chlorinated solvent concentrations detected in wells screened across shallow bedrock were 2.2 µg/L or less (Table 4.3). Based on available data, the presence of DNAPL at Site FT-1 is unlikely.

For the entire site, vinyl chloride accounted for 80 percent of the total detected chlorinated solvents in November 1995/May 1996; *cis*-1,2-DCE accounted for 14 percent; and, TCE and *trans*-1,2-DCE accounted for the remaining 6 percent.

One of the most straightforward methods for evaluating the occurrence and method of biodegradation of CAHs is to look at the distribution of target CAHs and the products of biodegradation (e.g., the daughter products) of those compounds. The presence of the daughter products cis-1,2-DCE, vinyl chloride, and ethene in samples collected from within the burn pit and immediately downgradient suggest that reductive dehalogenation is an active process at the site. At the same time, it is also useful to

look at the distribution of other contaminants that may be acting as sources of electron donors (e.g., BTEX).

A typical pattern for reductive dehalogenation (as presented by Vogel, 1994) would have TCE concentrations highest in the source area, with elevated DCE concentrations (consisting mostly of *cis*-1,2-DCE) within and just downgradient from the source area. Vinyl chloride concentrations could be present along the entire plume length, with the highest VC concentrations likely to be found near the downgradient end of the CAH plume. If VC is also being reductively dehalogenated, dissolved ethene may also be present downgradient of the source area. A similar pattern is observed at FT-1 with VC concentrations increasing downgradient from the source area, while TCE and cis-1,2-DCE concentrations decrease to less 1.2 µg/L immediately downgradient from the burn pit. Ethene was detected in four of the seven groundwater samples that also had VC contamination. The lack of a defined ethene plume may be the result of higher DO levels at the anaerobic downgradient fringe of the VC plume facilitating the complete mineralization of VC to carbon dioxide and water.

4.4.2 Geochemical Indicators

In addition to the contaminant distributions, geochemical indicators can be used to support the contention that biodegradation of BTEX and CAHs is ongoing at FT-01. As noted in Section 4.3, comparing concentrations and distributions of electron donors, electron acceptors, and byproducts of microbially mediated reactions can help indicate what types of processes are operating at a site. In addition, other geochemical parameters also can provide supporting evidence, including redox potential, alkalinity, and other changes in groundwater chemistry. In addition, other data can be useful for interpreting and confirming BTEX and CAH biodegradation mechanisms, such as volatile fatty acid concentrations. Table 4.5 summarizes groundwater geochemical data gathered during the RNA site investigation at Fairchild AFB. Geochemical indicators for site FT-1 are discussed in the following sections.

4.4.2.1 Dissolved Oxygen

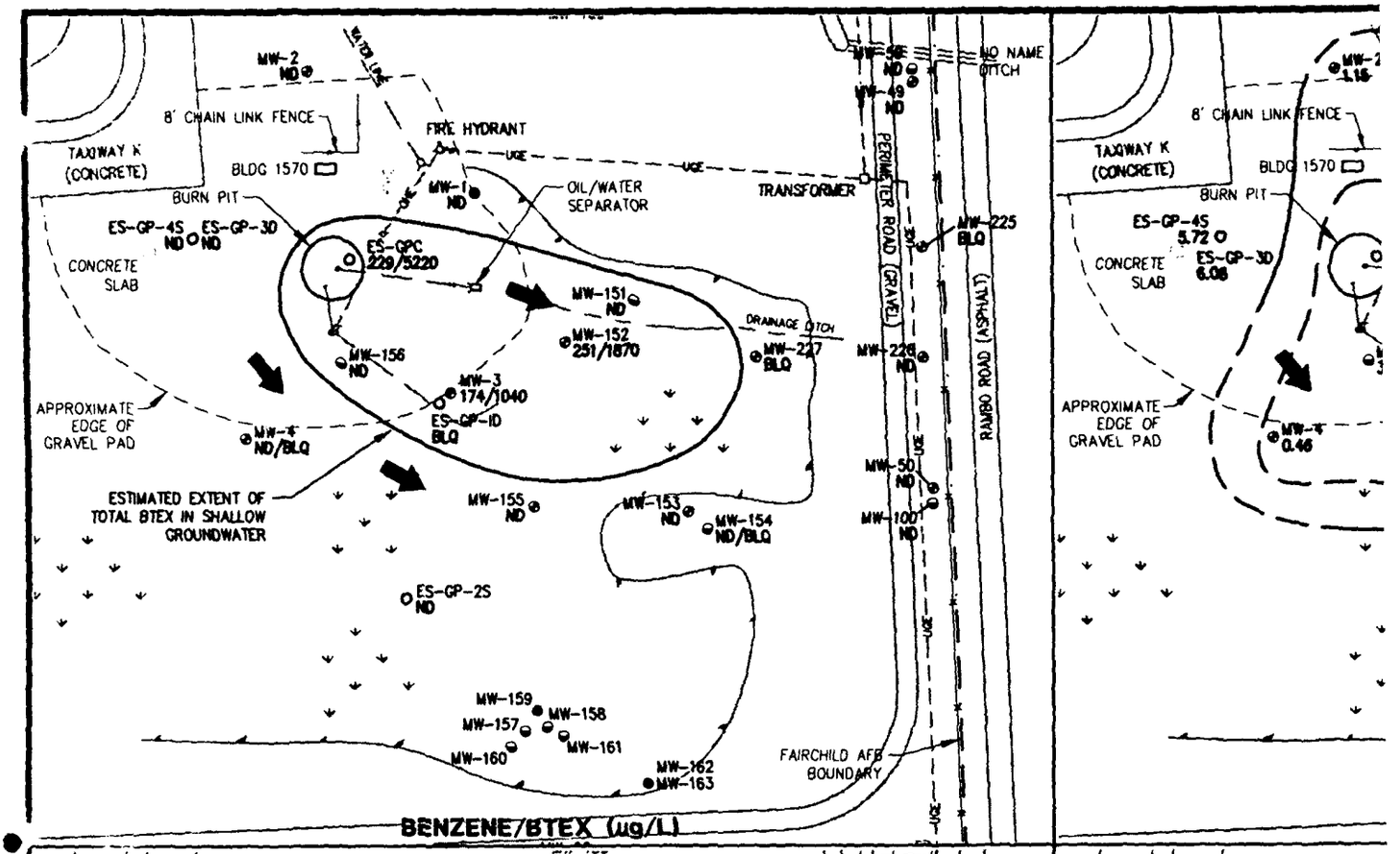
DO concentrations were measured at monitoring wells and points at the time of groundwater sampling in the November 1995 and May 1996. Table 4.5 summarizes measured DO concentrations. Figure 4.4 is an isopleth map showing the distribution of DO concentrations in shallow groundwater. These data provide strong evidence that aerobic biodegradation of the BTEX compounds is occurring at the site. Given background DO concentrations in the shallow groundwater (5.7 mg/L at monitoring point ES-GP-4S) and negligible DO concentrations within the burn pit area and the area occupied by the BTEX plume, it is likely that DO is an important electron acceptor at FT-01. Within the area of dissolved BTEX contamination, DO concentrations range from 0.5 mg/L to 0.86 mg/L (ES-GPC and MW-3, respectively).

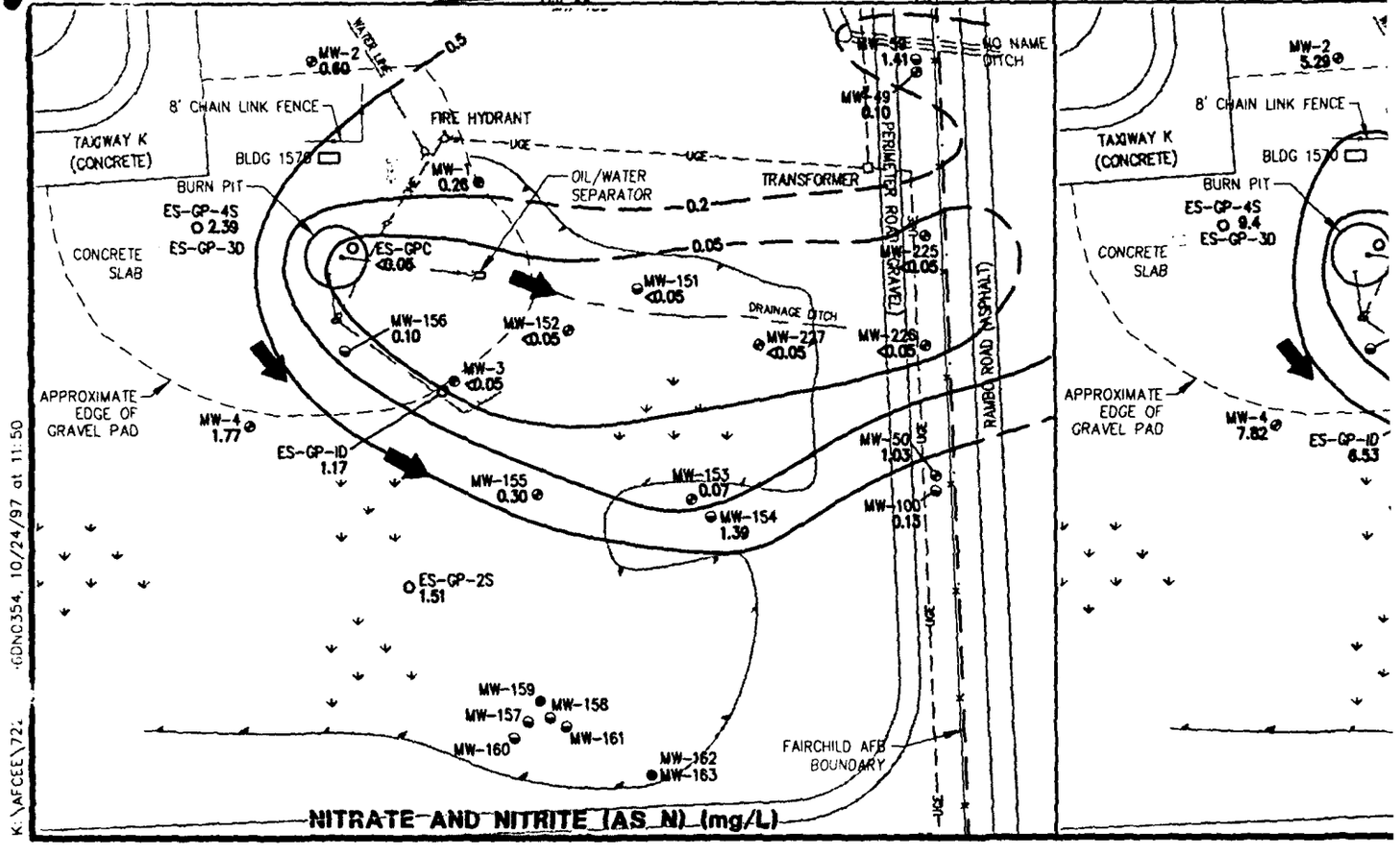
The stoichiometry of BTEX mineralization to carbon dioxide and water caused by aerobic microbial biodegradation is presented in Table 4.2. The average mass ratio of oxygen to total BTEX is approximately 3.14 to 1. This translates to the mineralization of approximately 0.32 mg of BTEX for every 1.0 mg of DO consumed. With an

TABLE 4.5
GROUNDWATER GEOCHEMICAL ANALYTICAL DATA
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Sample ID	Date Sampled	Temperature (°C)[a]	pH	Conductivity (ms/cm)[b]	Dissolved Oxygen (mg/L)[c]	Alkalinity (mg/L)	Redox Potential (mV)[d]	Carbon Dioxide (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	NO_2^- + NO_3^- (mg/L)	Ferrous Iron (mg/L)	Methane (mg/L)	Manganese (mg/L)	NH3 (mg/L)
ES-GP1	11/7/95	9.1	7.18	420	2.52	201	18.6	216	1.96	6.53	1.17	<0.05	1	0.6	0.19
ES-GP2	11/7/95	7.4	7.29	670	4.19	NA[e]	129	NA	2.01	7.02	1.51	NA	0.004	0.3	<0.05
ES-GP3	11/7/95	10.3	7.51	330	6.08	320	128	152	NA	NA	NA	<0.05	<0.001	NA	NA
ES-GP4	11/7/95	6.9	7.26	610	5.72	356	150	82	1.86	9.40	2.39	<0.05	<0.001	0.3	<0.05
ES-GPC	5/30/95	10.8	7.10	850	0.5	1260	-97.0	NA	3.25	<0.05	<0.05	20.5	16	NA	NA
MW-1	11/7/95	11.2	7.15	570	1.06	239	154	152	3.23	9.34	0.26	<0.05	0.003	1.5	<0.05
MW-2	11/7/95	10.0	7.16	470	1.15	197	179	142	1.86	5.29	0.60	<0.05	<0.001	<0.1	<0.05
MW-3	11/7/95	11.4	7.03	540	0.86	249	-127	250	2.32	0.84	<0.05	7.3	15	NA	0.23
MW-4	11/6/95	12.1	7.23	521	0.46	238	201	138	1.93	7.82	1.77	<0.05	<0.001	0.6	<0.05
MW-49	11/6/95	11.5	7.25	610	1.02	211	-18.4	256	13.6	1.77	0.10	0.20	0	2.0	0.27
MW-50	11/6/95	9.7	7.25	573	2.78	263	146	220	4.03	13.1	1.03	<0.05	0.001	<0.1	<0.05
MW-52	11/8/95	11.5	7.15	310	5.13	121	199	62	1.40	7.10	2.57	<0.05	<0.001	<0.1	<0.05
MW-52D	11/8/95	NA	7.16	NA	NA	122	NA	66	1.40	6.86	2.28	<0.05	NA	<0.1	<0.05
MW-53	11/8/95	10.2	7.55	230	4.35	75	204	40	94.0	6.37	1.75	<0.05	<0.001	<0.1	<0.05
MW-59	11/6/95	10.5	7.50	368	3.79	160	68.0	146	5.34	6.94	1.41	<0.05	<0.001	<0.1	<0.05
MW-61	11/8/95	10.8	7.83	270	2.37	105	14.0	72	1.47	8.93	<0.05	<0.05	0.001	<0.1	<0.05
MW-100	11/7/95	8.3	7.27	700	2.59	270	165	138	2.79	5.08	0.13	<0.05	0	0.3	<0.05
MW-151	11/7/95	8.6	7.27	230	1.48	72	98.1	84	1.75	7.28	<0.05	<0.05	<0.001	0.3	<0.05
MW-152	11/8/95	12.5	6.95	760	0.82	248	125	464	2.33	0.80	<0.05	22.3	19.06	7.5	2.24
MW-153	11/7/95	9.1	7.19	530	1.21	230	177	94	2.04	6.11	0.07	<0.05	0.45	<0.1	<0.05
MW-154	11/7/95	8.5	8.81	400	7.95	146	94.7	76	2.28	17.1	1.39	<0.05	<0.001	<0.1	<0.05
MW-155	11/6/95	10.2	7.21	459	0.88	143	156	108	2.20	6.73	0.30	<0.05	0.05	<0.1	<0.05
MW-156	11/6/95	10.5	8.48	275	3.7	158	-14.4	102	2.15	21.7	0.10	<0.05	0.004	N/A	<0.05
MW-225	11/6/95	10.7	7.30	478	1.09	219	112	198	2.76	6.60	<0.05	2.8	0.18	4.0	0.41
MW-226	11/6/95	10.3	7.20	471	1.29	239	76.2	224	2.25	3.83	<0.05	2.0	1.45	9.0	0.33
MW-227	11/6/95	9.4	7.21	459	0.96	324	-50.8	128	1.91	3.43	<0.05	0.4	4.19	4.0	0.12

[a] °C = degrees Celsius.
[b] ms/cm = microsiemens per centimeter.
[c] mg/L = milligrams per liter.
[d] mV = millivolts.
[e] NA = Data not available.





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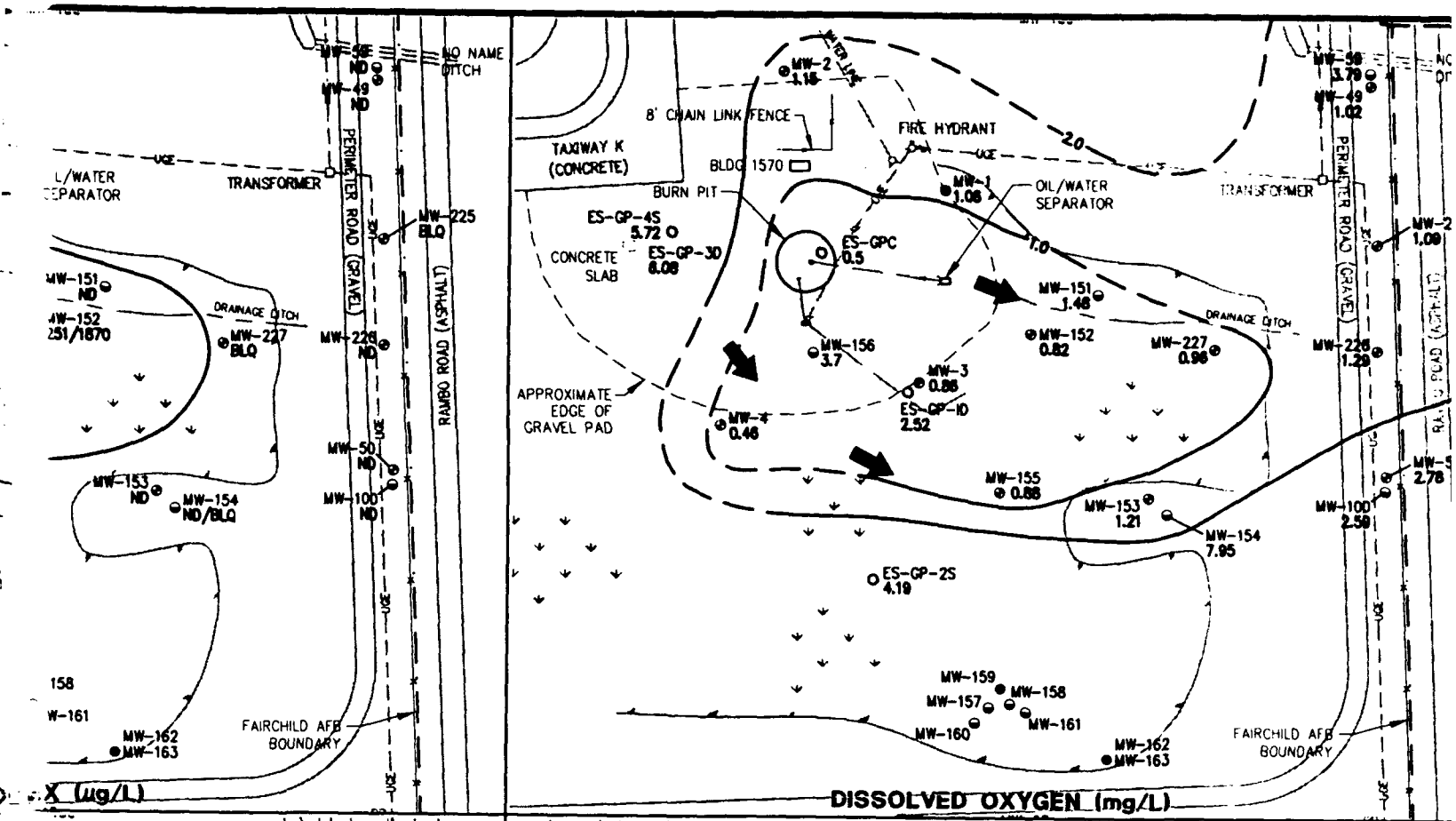
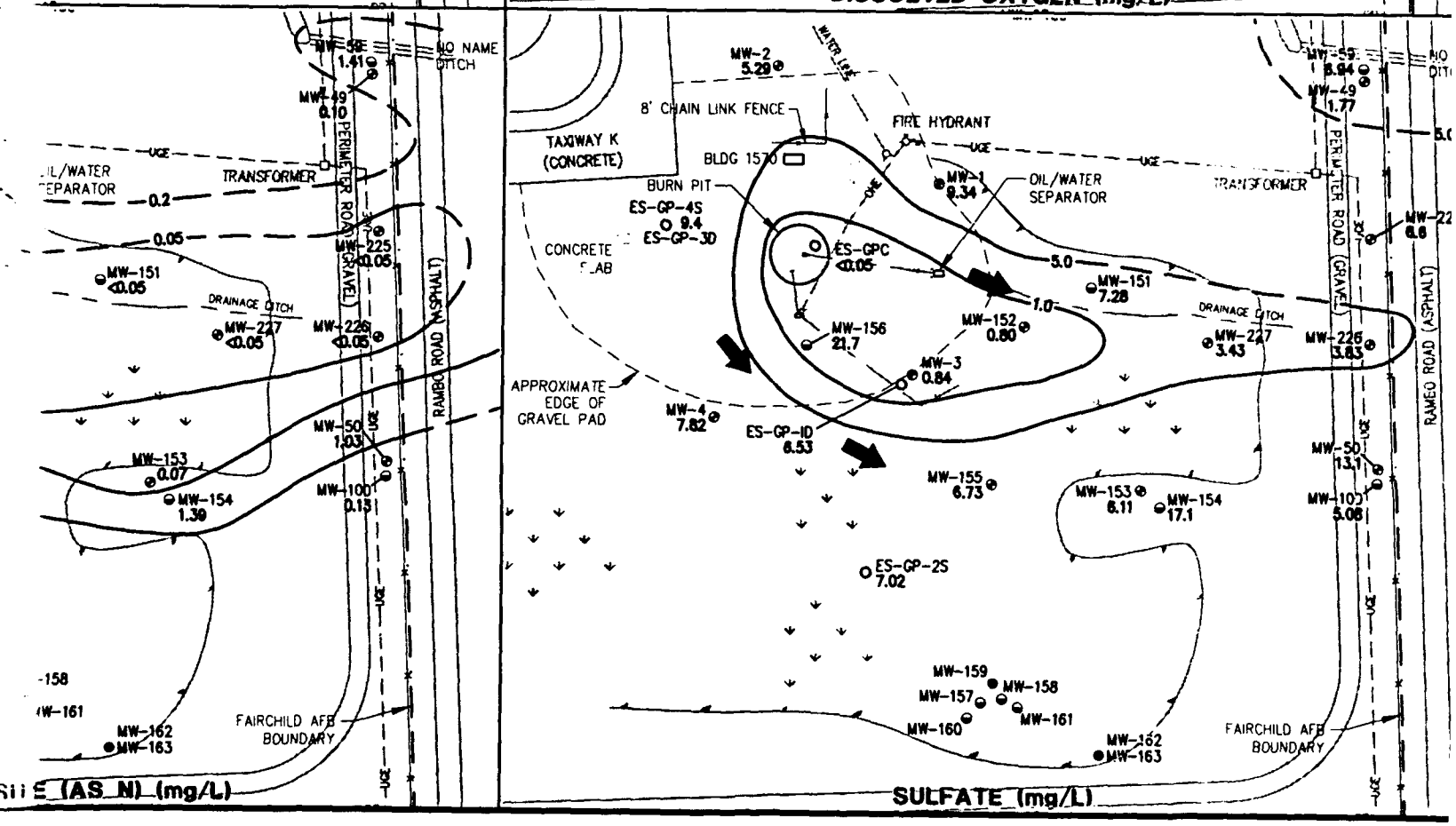
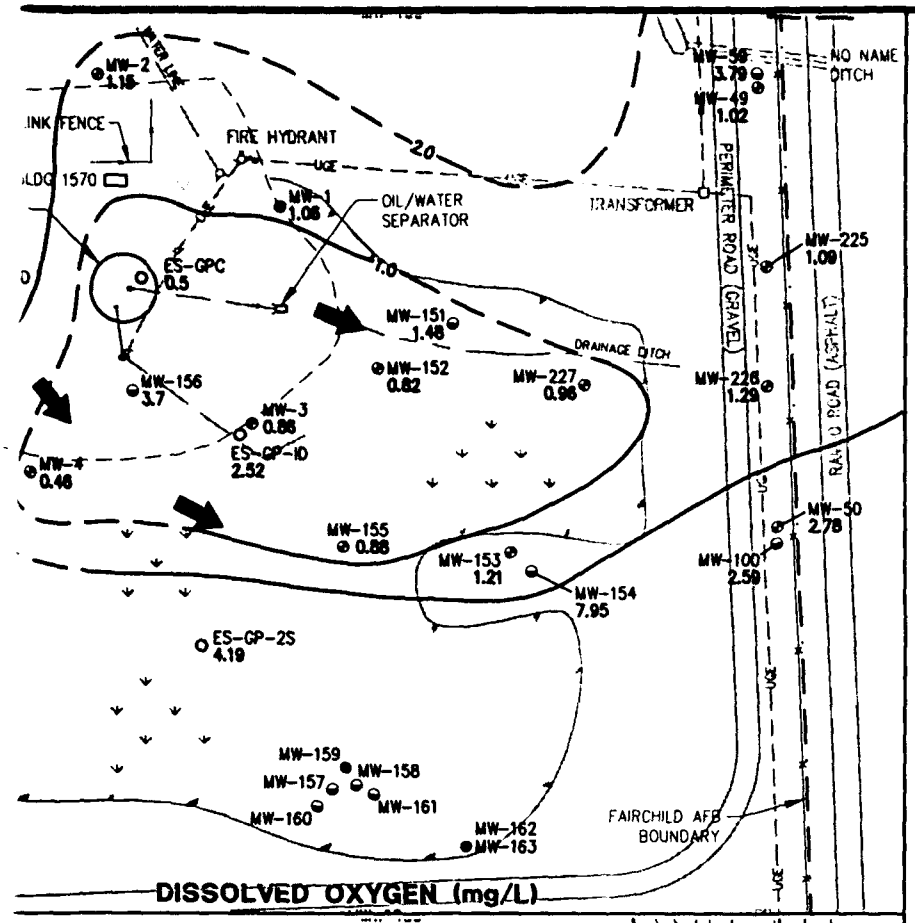
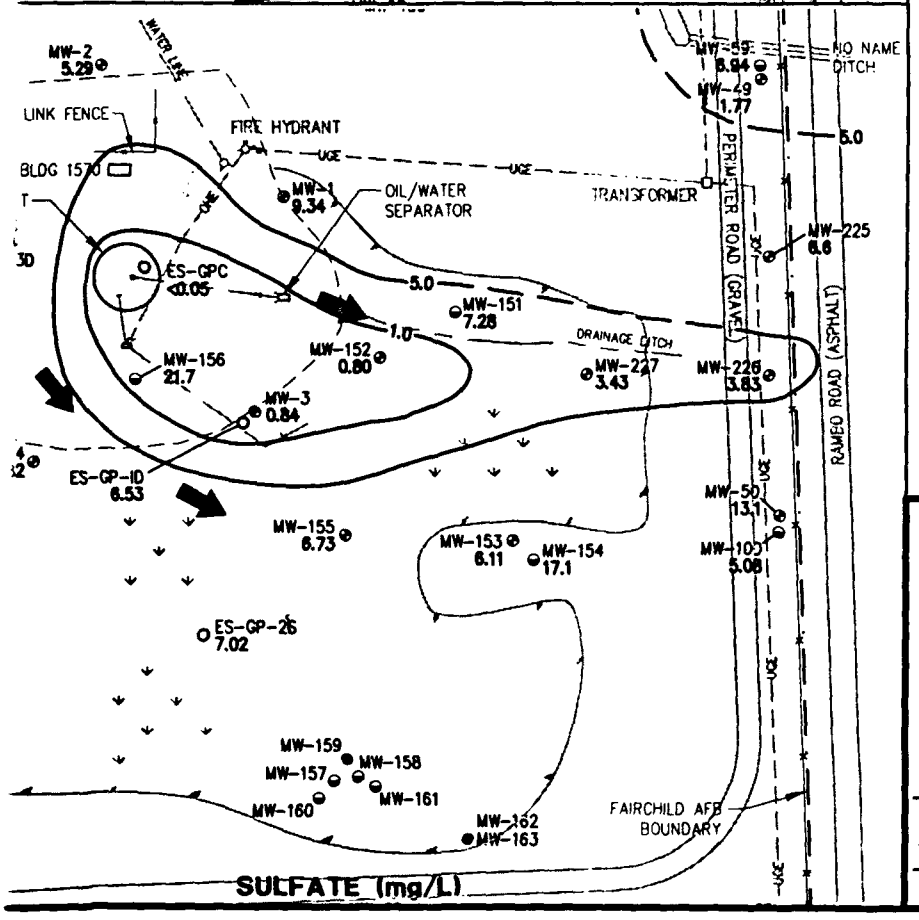

NO NAME DITCH
PERIMETER ROAD (GRAVEL)
RAMBO ROAD (ASPHALT)
TRANSFORMER
DRAINAGE DITCH
MW-225 BLQ
MW-227 BLQ
MW-226 ND
MW-151 ND
MW-152 251/1870
MW-153 ND
MW-154 ND/BLQ
MW-50 ND
MW-100 ND
MW-158
MW-161
MW-162
MW-163
FAIRCHILD AFB BOUNDARY
X (µg/L)
8' CHAIN LINK FENCE
FIRE HYDRANT
TAXIWAY K (CONCRETE)
BLDG 1570
BURN PIT
OIL/WATER SEPARATOR
CONCRETE SLAB
ES-GP-4S 5.72
ES-GP-3D 8.08
ES-GPC 0.5
MW-1 1.06
MW-2 1.15
MW-3 0.86
MW-4 0.46
MW-151 1.48
MW-152 0.82
MW-156 3.7
MW-227 0.98
ES-GP-1D 2.52
MW-155 0.88
MW-153 1.21
MW-154 7.95
ES-GP-2S 4.19
MW-159
MW-157
MW-158
MW-160
MW-161
MW-162
MW-163
APPROXIMATE EDGE OF GRAVEL PAD
2.0
1.0
DISSOLVED OXYGEN (mg/L)


NO NAME DITCH
PERIMETER ROAD (GRAVEL)
RAMBO ROAD (ASPHALT)
TRANSFORMER
DRAINAGE DITCH
MW-225 <0.05
MW-227 <0.05
MW-226 <0.05
MW-151 <0.05
MW-152 0.07
MW-153 0.07
MW-154 1.39
MW-50 1.03
MW-100 0.13
MW-158
MW-161
MW-162
MW-163
FAIRCHILD AFB BOUNDARY
E (AS N) (mg/L)
8' CHAIN LINK FENCE
FIRE HYDRANT
TAXIWAY K (CONCRETE)
BLDG 1570
BURN PIT
OIL/WATER SEPARATOR
CONCRETE SLAB
ES-GP-4S 9.4
ES-GP-3D
ES-GPC <0.05
MW-1 9.34
MW-2 5.29
MW-3 0.84
MW-4 7.82
MW-151 7.28
MW-152 0.80
MW-156 21.7
MW-227 3.43
ES-GP-1D 8.53
MW-155 6.73
MW-153 8.11
MW-154 17.1
ES-GP-2S 7.02
MW-159
MW-157
MW-158
MW-160
MW-161
MW-162
MW-163
APPROXIMATE EDGE OF GRAVEL PAD
0.2
0.05
5.0
1.0
SULFATE (mg/L)





LEGEND

- 0.10⊕ SHALLOW MONITORING WELL WITH ANALYTE CONCENTRATION
- 1.41⊖ SHALLOW BEDROCK MONITORING WELL WITH ANALYTE CONCENTRATION
- ● DEEP BEDROCK MONITORING WELL
- 1.17○ TEMPORARY MONITORING POINT WITH ANALYTE CONCENTRATION
- —0.5— LINE OF EQUAL ANALYTE CONCENTRATION (DASHED WHERE INFERRED)
- APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTE:

CONTOURED ON THE BASIS OF ANALYTE CONCENTRATIONS MEASURED AT SHALLOW MONITORING WELLS AND POINTS.

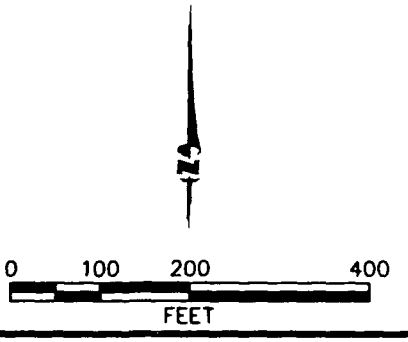


FIGURE 4.4

EXTENT OF OXIDIZED ELECTRON ACCEPTORS (NOVEMBER 1995)

Site FT-1
Remediation By Natural Attenuation TS
Fairchild Air Force Base, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

assumed background DO concentration of 5.7 mg/L, the shallow groundwater at this site has the capacity to assimilate 1.8 mg/L (1,800 µg/L) of total BTEX through aerobic biodegradation. This may be a conservative estimate of the assimilative capacity of DO because microbial cell mass production is not taken into account by the stoichiometry present in Table 4.2.

When cell mass production is accounted for, the mineralization of benzene to carbon dioxide and water is given by:

$$C_6H_6 + 2.5O_2 + HCO_3 + NH_4 \rightarrow C_5H_7O_2N + 2CO_2 + 2H_2O$$

From this it can be seen that 5 fewer moles of DO are required to mineralize 1 mole of benzene when cell mass production is taken into account. On a mass basis, the ratio of DO to benzene is given by:

Benzene $6(12) + 6(1) = 78$ gm

Oxygen $2.5(32) = 80$ gm

Mass Ratio of Oxygen to Benzene = 80/78 = 1.03:1

On the basis of these stoichiometric relationships, 1.03 mg of oxygen is required to mineralize 1 mg of benzene, if cell mass is being produced. Similar calculations can be made for toluene, ethylbenzene, and the xylenes. On the basis of these calculations, approximately 0.97 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of DO consumed.

Although this process results in more efficient utilization of electron acceptors, it is only applicable as the net cell mass of the microbial population continues to grow. Because groundwater contamination has been present at Site FT-1 for numerous years, it is possible that biomass production has reached equilibrium. In that case, the cell mass reaction equations would no longer apply.

4.4.2.2 Nitrate/Nitrite

Concentrations of nitrate and nitrite [as nitrogen (N)] were measured in groundwater samples collected in November 1995 and May 1996. Table 4.5 summarizes measured nitrate/nitrite (as N) concentrations. Figure 4.4 presents an isopleth map for nitrate/nitrite in shallow (unconsolidated deposits) groundwater. The data indicate reduced nitrate/nitrite concentrations within the groundwater BTEX plume, suggesting that nitrate is an important electron acceptor at this site. Nitrate/nitrite (as N) was detected in site groundwater at concentrations ranging from <0.05 mg/L within the BTEX plume to 2.4 mg/L upgradient from the plume.

In the absence of microbial cell production, the stoichiometry of BTEX mineralization to carbon dioxide, water, and nitrogen caused by denitrification is presented in Table 4.2. The average mass ratio of nitrate to total BTEX is approximately 4.9 to 1. This translates into the mineralization of approximately 0.20

mg of BTEX for every 1.0 mg of nitrate consumed. This ratio of nitrate consumption assumes that nitrate nitrogen is reported as nitrate ion (NO_3) instead of elemental nitrogen (N). The nitrate nitrogen concentrations shown in Table 4.4 are reported as N, and must be multiplied by 4.42 to be converted into nitrate nitrogen concentrations as NO_3.

Due to the variation of nitrate/nitrite levels between the BTEX plume boundaries and the background well a background nitrate/nitrite concentration of 10.6 mg/L was assumed (as NO_3) [nitrate/nitrogen (as N) in Table 4.2 was converted to nitrate/nitrogen (as NO_3) by multiplying by 4.42]. Therefore, the shallow groundwater at this site has the capacity to assimilate 2.12 mg/L (2,120 µg/L) of total BTEX during denitrification. Because biomass accumulation is not considered, the actual assimilative capacity attributable to denitrification could be somewhat higher.

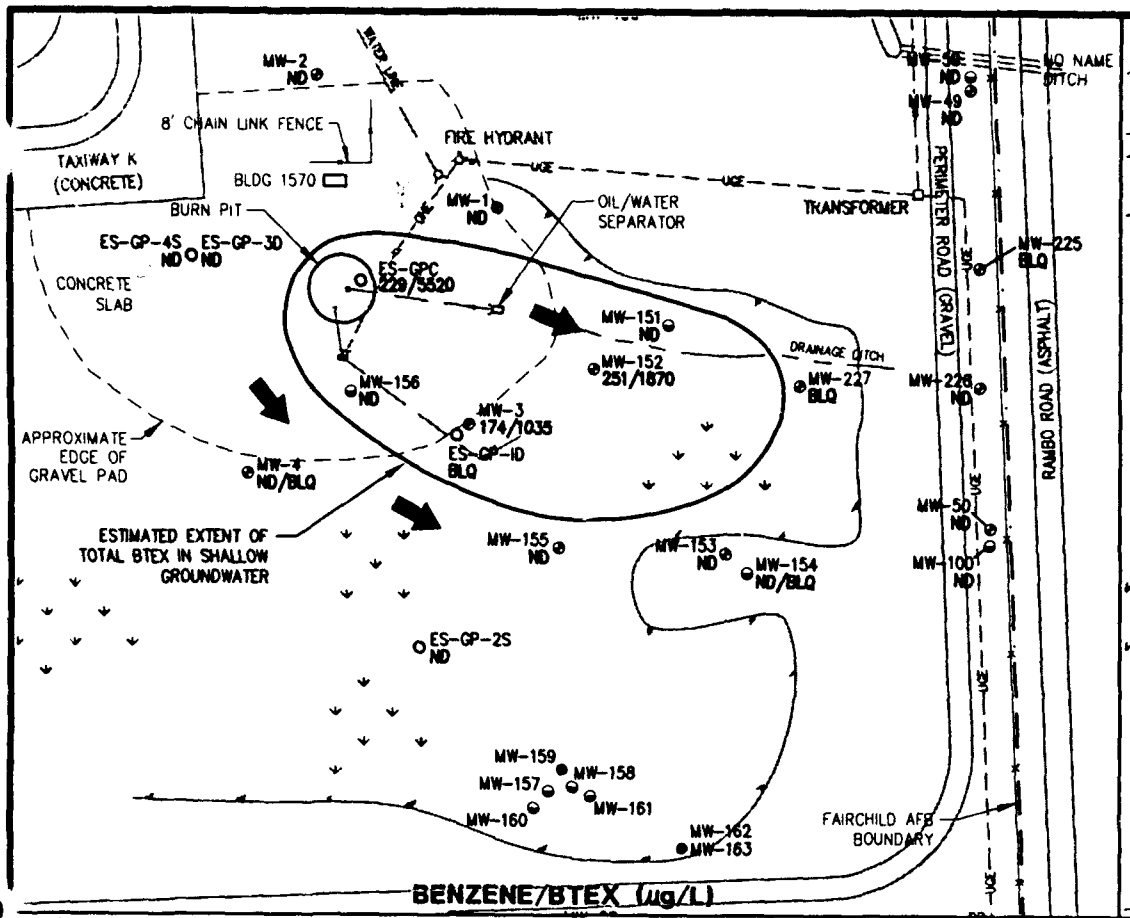
4.4.2.3 Sulfate

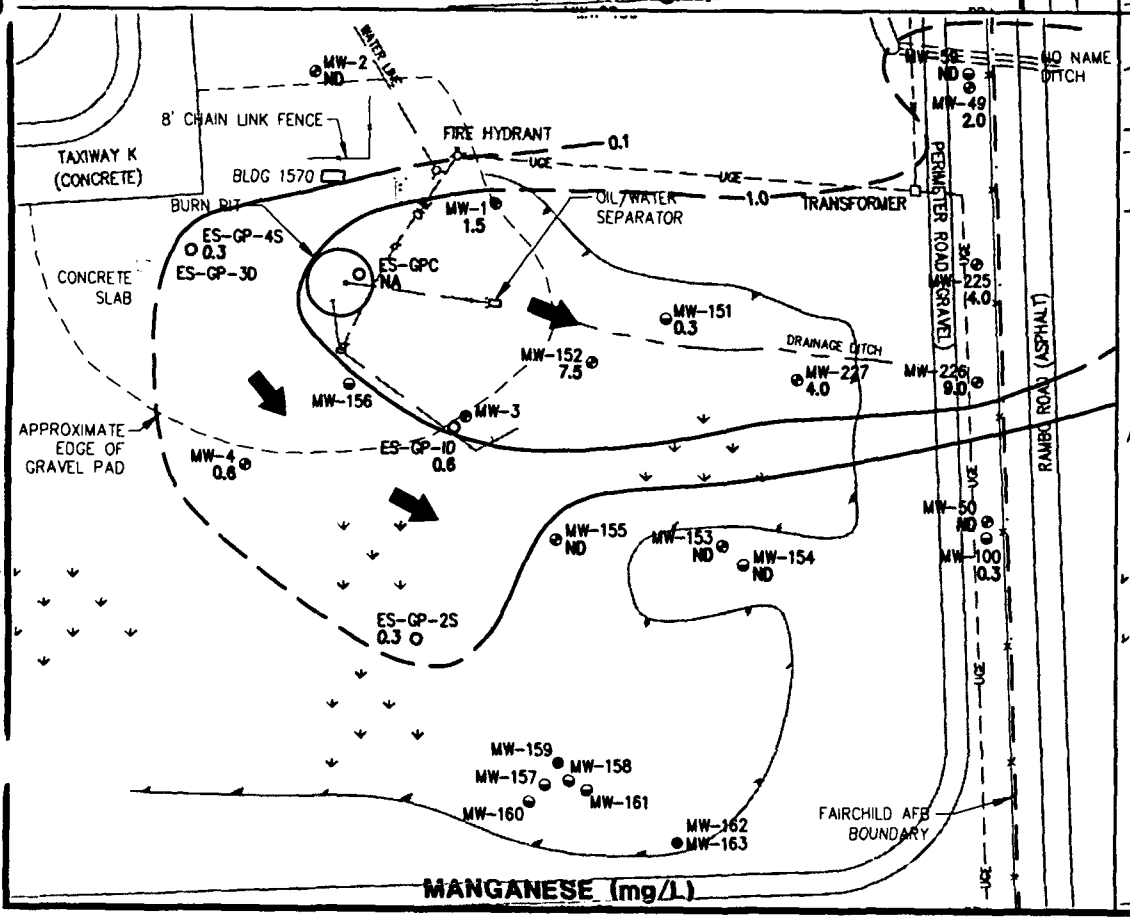
Sulfate concentrations were measured in groundwater samples collected in November 1995 and May 1996. Shallow sulfate concentrations at the site range from <0.05 mg/L near the burn pit to 13.1 mg/L at well MW-50. Table 4.5 summarizes measured sulfate concentrations. Figure 4.4 presents an isopleth map illustrating the areal extent of sulfate in groundwater. Comparison of the individual plumes on Figure 4.4 shows graphically that the area of depleted sulfate concentrations corresponds to the anaerobic (DO-depleted) portions of the BTEX plume. This is a strong indication that anaerobic biodegradation of the BTEX compounds is occurring at the site. In addition, the depleted sulfate concentrations suggest that reductive dehalogenation of TCE may be occurring at the site. The lowest sulfate concentration was measured in a groundwater sample from monitoring point location ES-GPC (<0.05 mg/L), which is located in the center of the burn pit.

The stoichiometry of BTEX mineralization to carbon dioxide, sulfur, and water by microbial sulfate reduction is presented in Table 4.2. The average mass ratio of sulfate to total BTEX is approximately 4.7 to 1. This translates to the mineralization of approximately 0.21 mg of total BTEX for every 1.0 mg of sulfate consumed. Sulfate concentrations at monitoring locations upgradient and at the plume fringe range from 9.4 mg/L to 13.1 mg/L, with an average concentration of 11.3 mg/L. Assuming a background concentration of 11.3 mg/L, the shallow groundwater at this site has the capacity to assimilate 2.4 mg/L (2,400 µg/L) of total BTEX through sulfate reduction. Because biomass accumulation is not considered, the actual assimilative capacity attributable to sulfate reduction could be somewhat higher.

4.4.2.4 Ferrous Iron

Ferrous iron (Fe^{2+}) concentrations were measured in groundwater samples collected in November 1995 and May 1996. Table 4.5 summarizes ferrous iron concentrations, and Figure 4.5 presents an isopleth map showing the distribution of ferrous iron in groundwater. Comparison of ferrous iron concentrations with the BTEX plume and





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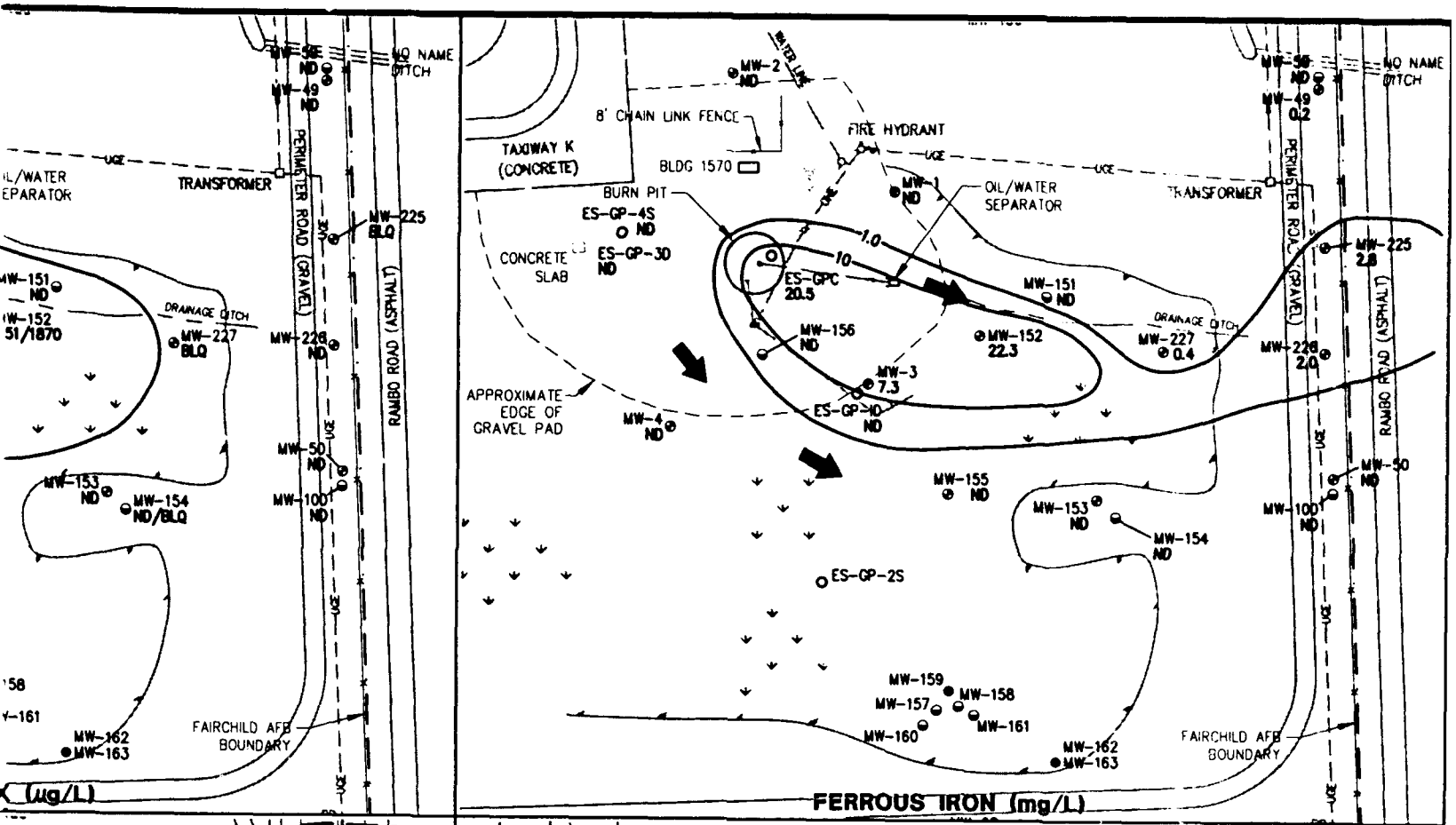
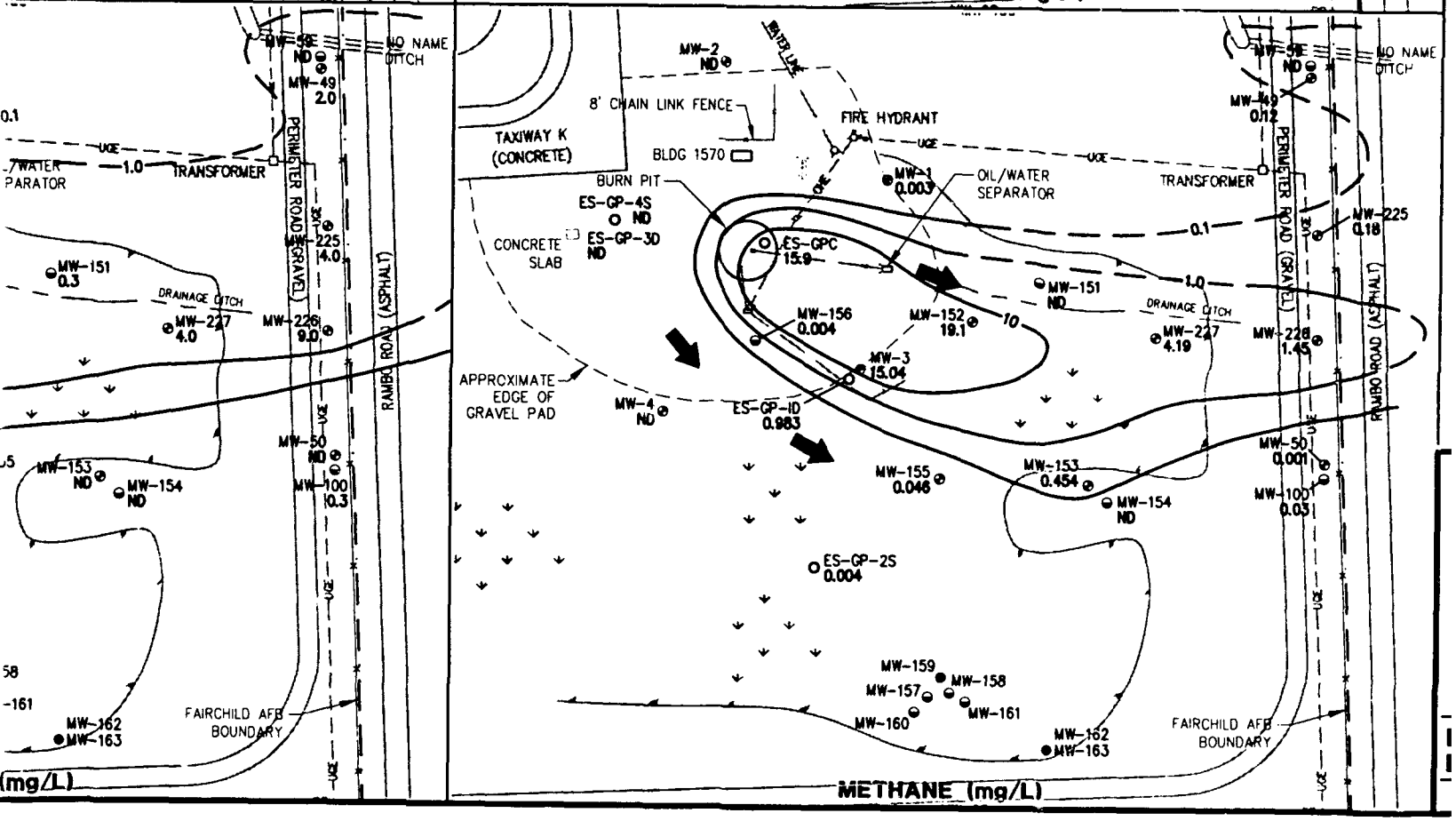
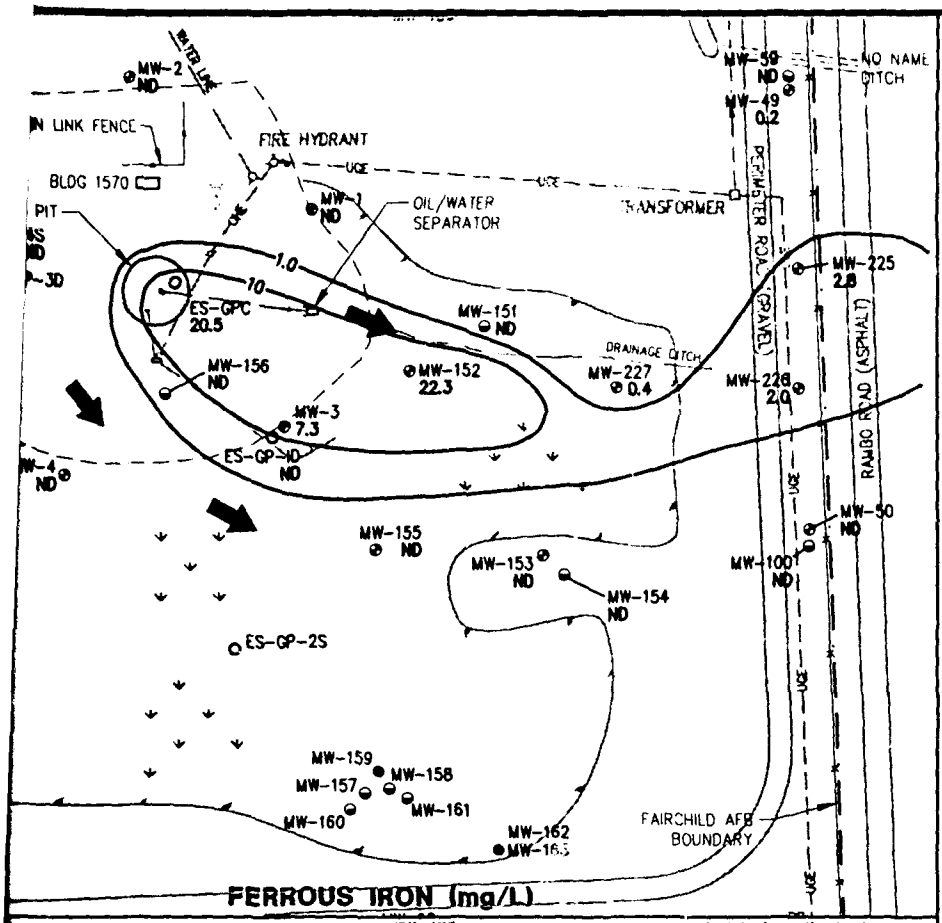

NO NAME DITCH
PERIMETER ROAD (GRAVEL)
RAMBO ROAD (ASPHALT)
TRANSFORMER
DRAINAGE DITCH
MW-225 BLQ
MW-227 BLQ
MW-226 ND
MW-151 ND
MW-152 51/1870
MW-153 ND
MW-154 ND/BLQ
MW-50 ND
MW-100 ND
MW-49 ND
MW-56E ND
FAIRCHILD AFB BOUNDARY
MW-162
MW-163
(µg/L)
8' CHAIN LINK FENCE
TAXIWAY K (CONCRETE)
BLDG 1570
FIRE HYDRANT
WATER LINE
OIL/WATER SEPARATOR
BURN PIT
ES-GP-4S ND
ES-GP-3D ND
CONCRETE SLAB
ES-GPC 20.5
MW-1 ND
MW-2 ND
MW-3 7.3
MW-4 ND
MW-156 ND
MW-152 22.3
MW-227 0.4
MW-225 2.8
MW-226 2.0
MW-49 0.2
MW-56E ND
MW-50 ND
MW-100 ND
MW-153 ND
MW-154 ND
MW-155 ND
MW-151 ND
ES-GP-ID ND
ES-GP-2S
MW-157
MW-158
MW-159
MW-160
MW-161
APPROXIMATE EDGE OF GRAVEL PAD
1.0
10
FERROUS IRON (mg/L)


NO NAME DITCH
PERIMETER ROAD (GRAVEL)
RAMBO ROAD (ASPHALT)
TRANSFORMER
DRAINAGE DITCH
MW-225 14.0
MW-227 4.0
MW-226 9.0
MW-151 0.3
MW-153 ND
MW-154 ND
MW-50 ND
MW-100 10.3
MW-49 2.0
MW-56E ND
FAIRCHILD AFB BOUNDARY
MW-162
MW-163
(mg/L)
8' CHAIN LINK FENCE
TAXIWAY K (CONCRETE)
BLDG 1570
FIRE HYDRANT
WATER LINE
OIL/WATER SEPARATOR
BURN PIT
ES-GP-4S ND
ES-GP-3D ND
CONCRETE SLAB
ES-GPC 15.9
MW-1 0.003
MW-2 ND
MW-3 15.04
MW-4 ND
MW-156 0.004
MW-152 19.1
MW-227 4.19
MW-225 0.18
MW-226 1.45
MW-49 0.12
MW-56E ND
MW-50 0.001
MW-100 0.03
MW-153 0.454
MW-154 ND
MW-155 0.046
MW-151 ND
ES-GP-ID 0.983
ES-GP-2S 0.004
MW-157
MW-158
MW-159
MW-160
MW-161
APPROXIMATE EDGE OF GRAVEL PAD
0.1
1.0
10
METHANE (mg/L)



LEGEND

<0.1 ⊕	SHALLOW MONITORING WELL WITH ANALYTE CONCENTRATION
0.3 ⊕	SHALLOW BEDROCK MONITORING WELL WITH ANALYTE CONCENTRATION
●	DEEP BEDROCK MONITORING WELL
0.6 ○	TEMPORARY MONITORING POINT WITH ANALYTE CONCENTRATION
—0.1—	LINE OF EQUAL ANALYTE CONCENTRATION (DASHED WHERE INFERRED)
⬅	APPROXIMATE DIRECTION OF GROUNDWATER FLOW
ND	NOT DETECTED

NOTE:
CONTOURED ON THE BASIS OF ANALYTE CONCENTRATIONS MEASURED AT SHALLOW MONITORING WELLS AND POINTS.

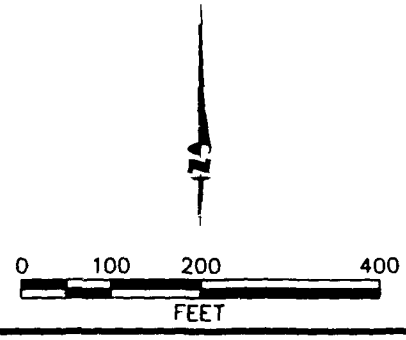


FIGURE 4.5

EXTENT OF BYPRODUCTS OF ELECTRON ACCEPTOR REDUCTION (NOVEMBER 1995)

Site FT-1
Remediation By Natural Attenuation TS
Fairchild Air Force Base, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

DO isopleth map (Figure 4.4) indicates that ferrous iron is being produced in the anaerobic portion of the BTEX plume due to the reduction of ferric iron hydroxide (Fe^{3+}) during anaerobic biodegradation of BTEX compounds. Background ferrous iron concentrations are as low as <0.1 mg/L, as measured at wells with little or no BTEX concentration. Groundwater samples from point ES-GPC and well MW-152 in the interior of the BTEX plume, had the highest ferrous iron concentrations, at 20.5 and 22.3 mg/L of Fe^{2+}, respectively. These relationships are a strong indication that anaerobic biodegradation of BTEX compounds is occurring in the shallow groundwater through iron reduction.

The stoichiometry of BTEX oxidation to carbon dioxide, ferrous iron, and water by microbial iron reduction is presented in Table 4.2. On average 37.5 moles of ferric iron hydroxide are required to metabolize one mole of total BTEX. Conversely, an average of 37.5 moles of ferrous iron are produced for each mole of total BTEX consumed. On a mass basis, this translates to approximately 21.8 mg ferrous iron produced for each 1 mg of total BTEX metabolized. Given a background ferrous iron concentration of <0.1 mg/L and a maximum ferrous iron concentration of 22.3 mg/L, the shallow groundwater has the capacity to assimilate approximately 1.0 mg/L (1,000 µg/L) of total BTEX through iron reduction. This is a conservative estimate of the assimilative capacity of iron because this calculation is based on observed ferrous iron concentrations and not on the amount of ferric hydroxide available in the aquifer. Therefore, iron assimilative capacity could be much higher.

Recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires microbial mediation by microorganisms with the appropriate enzymatic capabilities. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in the contaminated groundwater at the site are very strong indicators of microbial activity.

4.4.2.5 Methane

Methane concentrations were measured in groundwater samples collected in November 1995. Table 4.5 summarizes methane concentrations, which range from below the quantitation limit to 19.1 mg/L. Figure 4.5 presents an isopleth map showing the distribution of methane in groundwater. Comparison of the methane plume and the BTEX plume on Figure 4.5 illustrates that the areas with elevated total BTEX concentrations correlate well with elevated methane concentrations. Outside of the BTEX plume, the methane concentrations are <0.001 mg/L (the analytical quantitation limit). The highest methane concentrations were detected in the core of the BTEX plume, at monitoring wells MW-152 (19.1 mg/L) and MW-3 (15.0 mg/L), and monitoring point ES-GPC (15.9 mg/L). This is a strong indication that BTEX compounds are being biodegraded by the anaerobic process of methanogenesis at the

site. In addition, the high methane concentrations suggest that reductive dehalogenation of TCE, DCE, and vinyl chloride may be occurring at the site.

The stoichiometry of BTEX oxidation to carbon dioxide and methane by methanogenesis is presented in Table 4.4. On average, approximately 1 mg of total BTEX is mineralized for every 0.78 mg of methane produced. Given a maximum detected methane concentration of 19.1 mg/L, the shallow groundwater has the capacity to assimilate approximately 24.4 mg/L (24,400 µg/L) of total BTEX through methanogenesis. This is a conservative estimate of the assimilative capacity of methanogenesis because these calculations are based on observed methane concentrations and not on the amount of carbon dioxide (the electron acceptor for methanogenesis) available in the aquifer. Because methanogenesis produces more carbon dioxide than it consumes, an unlimited supply of carbon dioxide is theoretically available once the process of methanogenesis has been initiated. Therefore, methanogenesis is limited by the rate of reaction rather than the source of electron acceptors.

4.4.2.6 Reduction/Oxidation Potential

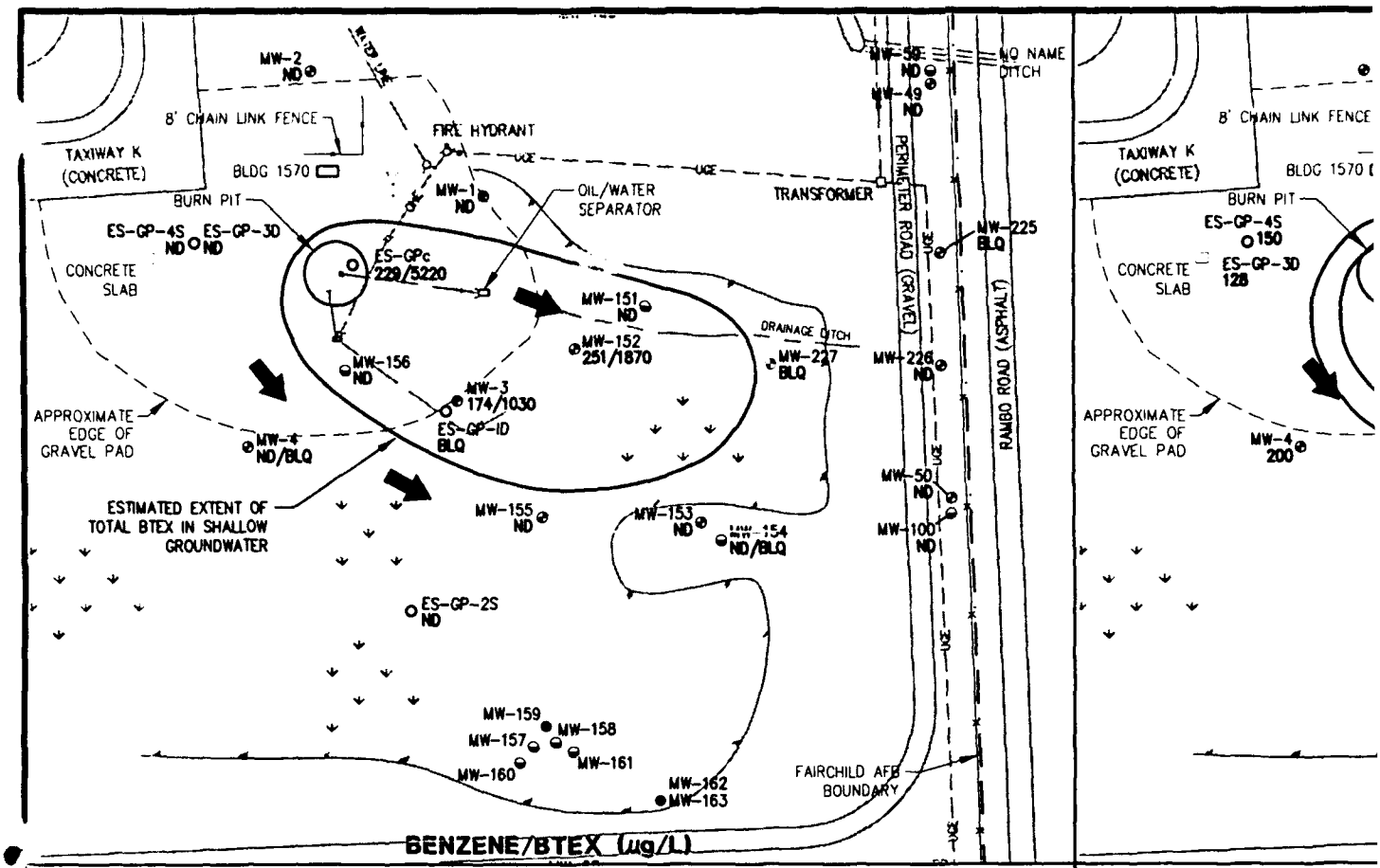
Redox potential is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system depends on which electron acceptors are being reduced by microbes during BTEX oxidation. Redox potentials were measured at groundwater monitoring wells/points in November 1995 and May 1996. These measurements are summarized in Table 4.5 and presented on Figure 4.6. The redox potentials, as measured relative to hydrogen, at the site range from -127 millivolts (mV) at monitoring well MW-3 to 200 mV at monitoring well MW-4. As expected, areas at the site with low redox potentials coincide with areas of high BTEX contamination, low DO, nitrate, and sulfate concentrations; and elevated ferrous iron and methane concentrations.

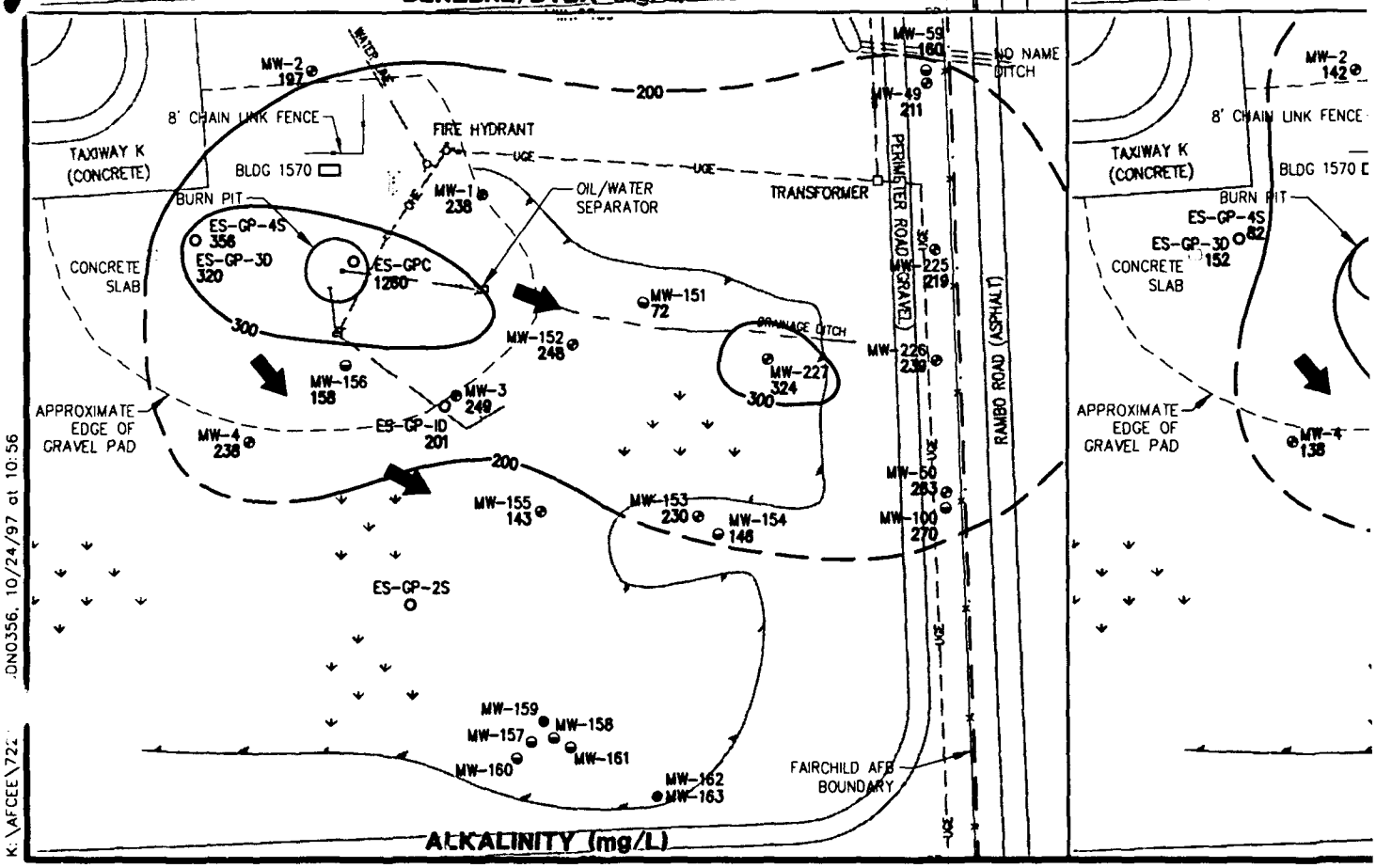
4.4.2.7 Volatile Fatty Acids

At monitoring wells MW-3 and MW-62, a groundwater sample was collected and analyzed for volatile fatty acids. This test is a gas chromatography/mass spectrometry (GC/MS) method wherein the samples are compared to a standard mixture containing a total of 58 phenols, aliphatic acids, and aromatic acids. Compounds in the standard mixture are generally associated with microbial processes that break down petroleum hydrocarbons. USEPA researchers reported that the sample from MW-3 contained 31 of the 58 compounds in the standard mixture that can be detected. In the MW-62 groundwater sample, 24 of the compounds were detected.

4.4.2.8 Alkalinity

Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids. In November 1995 and May 1996, total alkalinity (as calcium carbonate) was measured in groundwater samples. These measurements are summarized in Table 4.5. Figure 4.6 presents an isopleth map illustrating the increase in alkalinity in the areas of high BTEX concentration. Total





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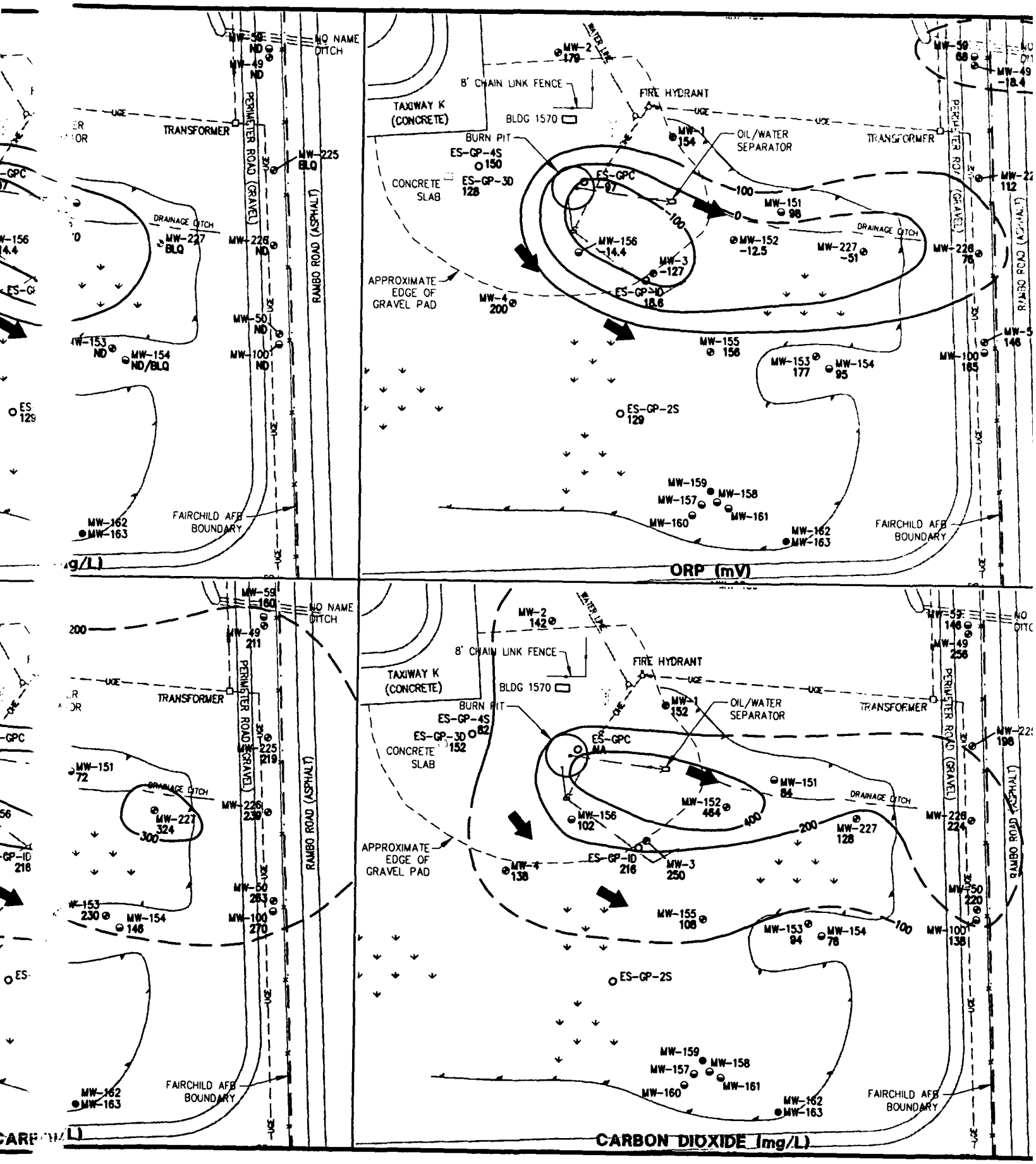
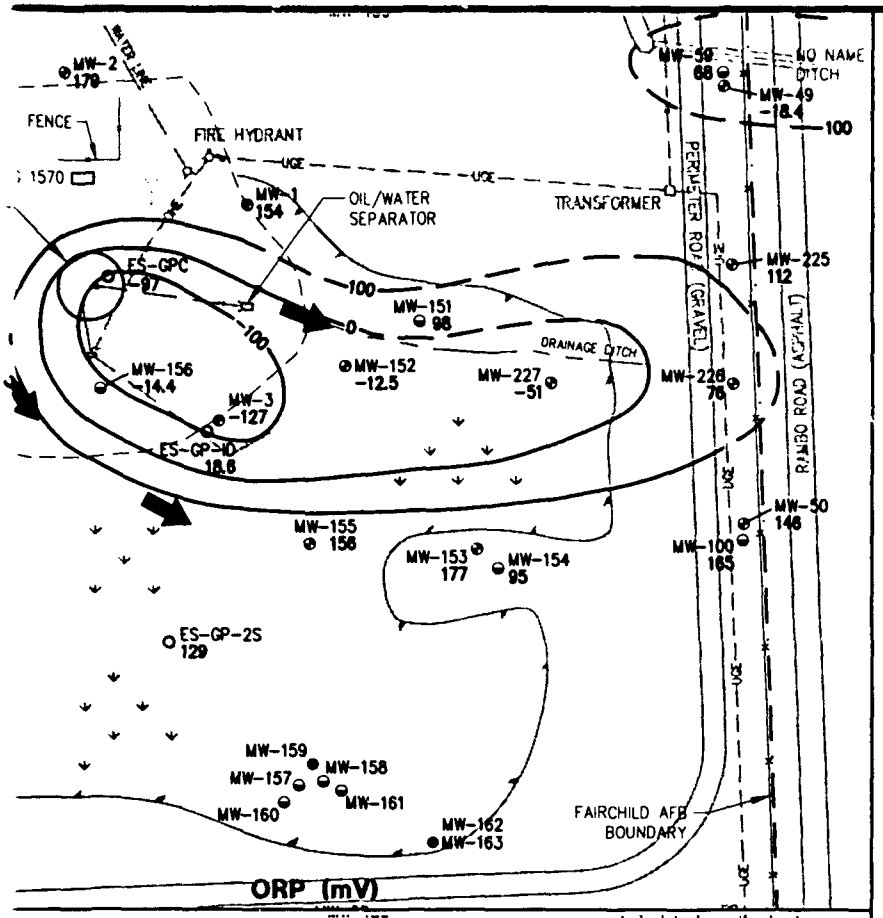
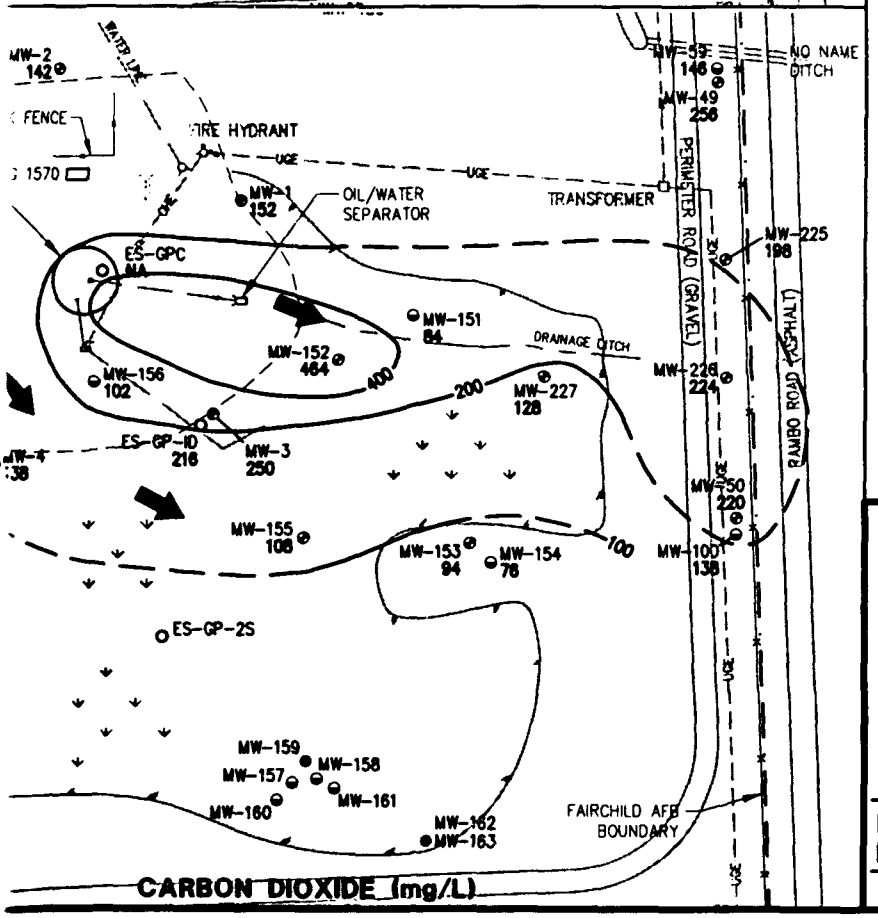


NO NAME DITCH
TRANSFORMER
PERIMETER ROAD (GRAVEL)
RAMBO ROAD (ASPHALT)
DRAINAGE DITCH
FAIRCHILD AFB BOUNDARY
MW-59 ND
MW-49 ND
MW-225 BLQ
MW-227 BLQ
MW-226 ND
MW-50 ND
MW-100 ND
MW-153 ND
MW-154 ND/BLQ
MW-162
MW-163
8' CHAIN LINK FENCE
TAXIWAY K (CONCRETE)
BLDG 1570
FIRE HYDRANT
BURN PIT
OIL/WATER SEPARATOR
CONCRETE SLAB
ES-GP-4S 150
ES-GP-3D 128
ES-GPC 97
MW-1 154
MW-2 179
MW-151 98
MW-156 14.4
MW-152 -12.5
MW-227 -51
MW-3 -127
ES-GP-ID 18.6
MW-4 200
APPROXIMATE EDGE OF GRAVEL PAD
MW-155 156
MW-153 177
MW-154 95
ES-GP-2S 129
MW-159
MW-158
MW-157
MW-161
MW-160
MW-162
MW-163
MW-59 68
MW-49 -18.4
MW-226 76
MW-100 165
MW-2 142
MW-1 152
ES-GP-4S 82
ES-GP-3D 152
ES-GPC MA
MW-151 84
MW-152 464
MW-156 102
MW-227 128
ES-GP-ID 216
MW-3 250
MW-4 138
MW-155 108
MW-153 94
MW-154 78
MW-59 146
MW-49 256
MW-226 224
MW-50 220
MW-100 138
ORP (mV)
CARBON DIOXIDE (mg/L)





LEGEND

−51 ⊕	SHALLOW MONITORING WELL WITH ANALYTE LEVEL
165 ⊖	SHALLOW BEDROCK MONITORING WELL WITH ANALYTE LEVEL
●	DEEP BEDROCK MONITORING WELL
150 ○	TEMPORARY MONITORING POINT WITH ANALYTE LEVEL
—100—	LINE OF EQUAL ANALYTE LEVEL (DASHED WHERE INFERRED)
⬅	APPROXIMATE DIRECTION OF GROUNDWATER FLOW
ND	NOT DETECTED

NOTE:
CONTOURED ON THE BASIS OF ANALYTE LEVELS MEASURED AT SHALLOW MONITORING WELLS AND POINTS.

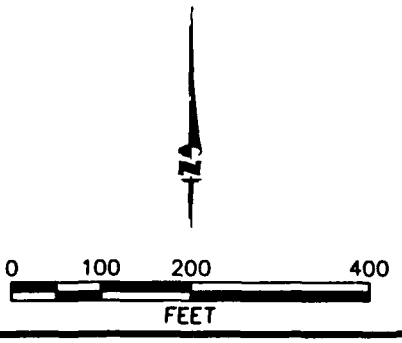


FIGURE 4.6

ADDITIONAL GEOCHEMICAL INDICATORS (NOVEMBER 1995)

Site FT-1
Remediation By Natural Attenuation TS
Fairchild Air Force Base, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

alkalinity at the site ranges from 72 mg/L at well MW-151 to 1,260 mg/L in a groundwater sample from the ES-GPC in burn pit. When compared with the BTEX plume, the elevated alkalinity isopleths correlate with the groundwater BTEX plume. The total background alkalinity at FT-08 is in the moderate range for groundwater. The increase in alkalinity in the areas of groundwater BTEX contamination is in response to increased carbon dioxide levels that result from BTEX biodegradation. Increasing alkalinity acts as a buffer to weakly acidic conditions brought about by an increase in carbon dioxide.

4.4.2.9 Carbon Dioxide in Groundwater

Carbon dioxide is produced in the plume area as a byproduct of aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis (Table 4.2). Groundwater carbon dioxide measurements were collected from site monitoring wells in November 1995. Table 4.5 summarizes the groundwater carbon dioxide measurements, and Figure 4.6 illustrates the lateral extent of the elevated carbon dioxide levels present at FT-01. Comparison of the area of elevated carbon dioxide with the dissolved BTEX plume further supports the inference that biodegradation of BTEX compounds is occurring.

4.4.2.10 pH

The pH of a solution is the negative logarithm of the hydrogen ion concentration [H^+]. pH was measured for groundwater samples collected from groundwater monitoring locations in November 1995. These measurements are summarized in Table 4.5. Groundwater pH measured at the site ranges from 6.95 to 8.81 standard units. This range of pH is within the optimal range for biologic activity (Atlas, 1988).

4.4.2.11 Temperature

Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with high temperatures generally resulting in higher growth rates. Groundwater temperature measurements made in November 1995 and May 1996 are summarized in Table 4.5. Temperatures in the aquifer varied from 6.9 degrees Celsius (°C) to 12.5 °C. These are relatively low temperatures for shallow groundwater; recent work suggests that biologic activity in aquifers found in colder climates is comparable to normal temperature range aquifers (Herrington *et al.*, 1996).

4.4.3 Expressed Assimilative Capacity for BTEX Degradation

The data presented in the preceding sections suggest that mineralization of BTEX compounds is occurring through the microbially mediated processes of aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis. On the basis of the stoichiometry presented in Table 4.4, the expressed BTEX assimilative capacity of groundwater at FT-1 is at least 31 mg/L (Table 4.6).

TABLE 4.6
EXPRESSED ASSIMILATIVE CAPACTIY OF SITE GROUNDWATER
SITE FT-1
REMEDAITON BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Electron Acceptor or Process	Assimilative Capacity (µg/L)
Dissolved Oxygen	1,800
Nitrate	2,120
Iron Reduction	1,000
Sulfate	2,400
Methanogenesis	24,400
Expressed Assimilative Capacity	31,700

A closed system containing 2 liters of water can be used to help visualize the physical meaning of assimilative capacity. Assume that the first liter contains no fuel hydrocarbons, but it contains fuel-degrading microorganisms and has an assimilative capacity of exactly "*x*" mg of fuel hydrocarbons. The second liter has no assimilative capacity; however, it contains fuel hydrocarbons. As long as these 2 liters of water are kept separate, the biodegradation of fuel hydrocarbons will not occur. If these 2 liters are combined in a closed system, biodegradation will commence and continue until the fuel hydrocarbons are depleted, the electron acceptors are depleted, or the environment becomes acutely toxic to the fuel-degrading microorganisms. Assuming a nonlethal environment, if less than "*x*" mg of fuel hydrocarbons are in the second liter, all of the fuel hydrocarbons will eventually degrade given a sufficient time; likewise, if greater than "*x*" mg of fuel hydrocarbons were in the second liter of water, only "*x*" mg of fuel hydrocarbons would ultimately degrade.

The groundwater beneath a site is an open system, which continually receives additional electron acceptors from the flow of the aquifer and the percolation of precipitation. This means that the assimilative capacity is not fixed as it would be in a closed system, and therefore cannot be compared directly to contaminant concentrations in the groundwater. Rather, the expressed assimilative capacity of groundwater is intended to serve as a qualitative tool. The fate of BTEX in groundwater and the potential impact to receptors is dependent on the relationship between the kinetics of biodegradation and the solute transport velocity (Chapelle, 1994). This significant expressed assimilative capacity is a strong indicator that biodegradation is occurring; however, it is not a guarantee that biodegradation will proceed to completion before potential downgradient receptors are impacted.

At FT-1, the groundwater appears to have sufficient assimilative capacity to degrade the observed dissolved BTEX and limit plume migration over time. In addition, the calculations of assimilative capacity presented in the earlier sections may be conservative because they do not account for microbial cell mass production, and the measured concentrations of ferrous iron and methane may not be the maximum

achievable. There is also a potential for the influx of electron acceptors (particularly oxygen) through rainwater infiltration at the site. The addition of this water may further enhance the assimilative capacity of the site groundwater.

4.5 DISCUSSION

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of jet fuel and gasoline, including the BTEX compounds (e.g., Jamison *et al.*, 1975; Atlas, 1981, 1984, 1988; Gibson and Subramanian, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, and 1990; Barker *et al.*, 1987; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989 and 1990; Cozzarelli *et al.*, 1990; Leahy and Colewell, 1990; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Ball *et al.*, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991; Edwards *et al.*, 1991 and 1992; Evans *et al.*, 1991a and 1991b; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Hutchins *et al.*, 1991a and 1991b; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). Biodegradation of fuel hydrocarbons can occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the aquifer and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms.

Chlorinated solvents also can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). Biodegradation of CAHs, while similar in principle to biodegradation of BTEX, typically results from a more complex series of processes.

Comparison of BTEX, CAH, electron acceptor, and biodegradation byproduct isopleth maps for FT-1 provides strong qualitative geochemical evidence of the biodegradation of BTEX and chlorinated solvent compounds. Site groundwater data for electron acceptors and degradation byproducts at FT-1 indicate that natural attenuation of hydrocarbons in the shallow aquifer may be occurring by aerobic oxidation, denitrification, ferric iron reduction, sulfate reduction, methanogenesis, and reductive dehalogenation. This is evidenced by significant changes in groundwater geochemistry in comparison to background conditions. Areas of the site which show the greatest variation in concentrations of geochemical parameters generally correspond well with areas of low redox potential, high BTEX concentrations, and an accumulation of CAH daughter products. Section 5 presents calculations that demonstrate that contaminant mass is being removed from site groundwater.

The expressed assimilative capacity of groundwater at this site is approximately 31,700 µg/L (Table 4.6). Furthermore, the presence of dissolved chlorinated solvents

through the core of the plume could contribute to a still higher assimilative capacity. Therefore, the site assimilative capacity appears to be sufficient to limit migration of dissolved BTEX compounds and low-molecular weight chlorinated solvent compounds (e.g., vinyl chloride). Nevertheless, the ultimate fate of BTEX and CAHs in groundwater and the potential impact to receptors is dependent on the relationship between the kinetics of biodegradation and the solute transport velocity rather than the expressed assimilative capacity of site groundwater.

SECTION 5

GROUNDWATER MODEL

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help estimate degradation rates for dissolved benzene at the FT-1 site and to help predict the future migration of this compounds, Parsons ES numerically modeled the fate and transport of the dissolved BTEX plume. The modeling effort had three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of biodegradation, advection, dispersion, and sorption; 2) to assess the potential for exposure of downgradient receptors to contaminant concentrations that exceed regulatory standards intended to be protective of human health and the environment; and 3) to provide further technical support for the evaluation of the RNA option. The models were developed using site-specific data and conservative assumptions about governing physical and chemical processes. Due to the conservative nature of the model input, the reduction in contaminant mass resulting from natural attenuation is expected to exceed model predictions. This analysis is not intended to represent a baseline assessment of potential risks posed by site contamination.

The Bioplume II code was used to estimate the potential for dissolved BTEX migration and degradation by natural mechanisms operating at FT-01. The Bioplume II model incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. The model is based upon the USGS Method of Characteristics (MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The model was modified by researchers at Rice University to include a biodegradation component that is activated by a superimposed DO plume. On the basis of the work of Borden and Bedient (1986), the model assumes a reaction between DO and BTEX that is instantaneous relative to the advective groundwater velocity. Bioplume II solves the USGS 2-D solute transport equation twice, once for hydrocarbon concentrations in the aquifer and once for a DO plume. The two plumes are combined using superposition at every particle move to simulate the instantaneous biologically mediated reaction between hydrocarbons and oxygen.

In recent years it has become apparent that anaerobic processes such as denitrification, iron reduction, sulfate reduction, and methanogenesis can be important BTEX degradation mechanisms (Grbic´-Galic´, 1990; Beller *et al.*, 1992; Edwards *et al.*, 1992; Edwards and Grbic´-Galic´, 1992; Grbic´-Galic´ and Vogel, 1987; Lovley *et al.*, 1989; Hutchins, 1991). Because geochemical evidence supports the occurrence of anaerobic biodegradation processes at Site FT-1 (Section 4.4.2), the combined

processes of aerobic and anaerobic biodegradation were considered in calculating BTEX fate and transport at the site. The following subsections discuss in detail the input parameters, the model assumptions, the model calibration, and the simulation results.

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

Prior to developing a groundwater model, it is important to determine if sufficient data are available to provide a reasonable estimate of aquifer conditions. In addition, it is important to ensure that any limiting assumptions can be justified. The most important assumption made when using the Bioplume II model is that oxygen-limited biodegradation of fuel hydrocarbons is occurring at the site. The Bioplume II model assumes that the limiting factors for BTEX biodegradation are: 1) the presence of an indigenous hydrocarbon-degrading microbial population, and 2) sufficient background electron acceptor concentrations. Data and information presented in Sections 3 and 4 suggest that oxygen, nitrate, ferric hydroxide, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for aerobic and anaerobic biodegradation of BTEX.

On the basis of the data presented in Section 3, the shallow aquifer is vertically defined by medium- to coarse-grained sands overlying a basalt bedrock. Within the basalt, a shallow basalt bedrock aquifer occupies the fractured upper portions of the bedrock layer. The middle region of the shallow basalt flow is more competent with less fracturing and acts as an aquitard. The majority of dissolved BTEX contamination preferentially migrates from the site in the sands overlying the basalt. Leakage through the unconsolidated sands into the upper fractured bedrock is occurring and was incorporated into the model. Lithologic data from soil borings suggest that the base of the shallow unconsolidated aquifer is defined by the top fractured basalt bedrock at approximately 20 feet bgs. Minor changes in site topography, such as the abovegrade gravel pad, may be responsible for a slight change in groundwater flow direction across the site. Groundwater enters the site from the west. Groundwater elevations suggest that the shallow groundwater at the site flows to the east-southeast near the source of the plume (near ES-GPC), then flows eastward downgradient from the gravel pad (near MW-152) (Figure 3.5).

The shallow unconsolidated layer above the basalt bedrock was conceptualized and modeled as a shallow unconfined aquifer composed of medium- to coarse-grained sand (Figures 3.2, 3.3, and 3.4). The average saturated thickness of this layer was estimated at 10 feet. The use of a 2-D model is appropriate at the FT-1 site because the shallow saturated interval (acting as the dominant transport pathway) is relatively thin and homogeneous. Because contamination previously detected in the shallow basalt layer appears to be under similar hydrologic and geochemical conditions, similar contaminant fate and transport conditions would be anticipated.

Dissolved BTEX is known to originate from residual soil contamination present in the shallow soils within the burn pit. Contaminated soils at the site have not been remediated; however, the ROD for site FT-1 specifies the installation of a bioventing

system and two air sparging walls east of the site adjacent to the gravel pad and parallel to the perimeter road. The remedial requirements of the ROD specify that benzene be reduced to below a concentration of 5 µg/L in groundwater throughout the plume. Given the current site use, additional fuel releases are not expected at the site in the future; therefore, only BTEX contamination leaching from current residual fuel contamination in site soils was considered as a continuing source for the dissolution of BTEX into groundwater over time.

5.3 INITIAL MODEL SETUP

The setup for this model was based on available site data. Where site-specific data were not available (e.g., effective porosity), reasonable assumptions for the types of materials that make up the shallow aquifer were made on the basis of widely accepted literature values. The following sections describe the basic model setup. Those Bioplume II model parameters that were varied during model calibration are discussed in Section 5.4.

5.3.1 Grid Design and Boundary Conditions

The maximum grid size for the Bioplume II model is limited to 20 columns by 30 rows. The dimension of each column and row can range from 0.1 to 999.9 feet. A 20- by 30-cell grid was used to model the FT-1 site. Each grid cell was 50 feet long by 50 feet wide. The grid was oriented so that the 30-cell dimension was parallel to the east-southeast groundwater flow direction. The grid includes the existing BTEX plume and encompasses an area of 1.5 million square feet (approximately 34 acres). The full extent of the model grid is indicated on Figure 5.1.

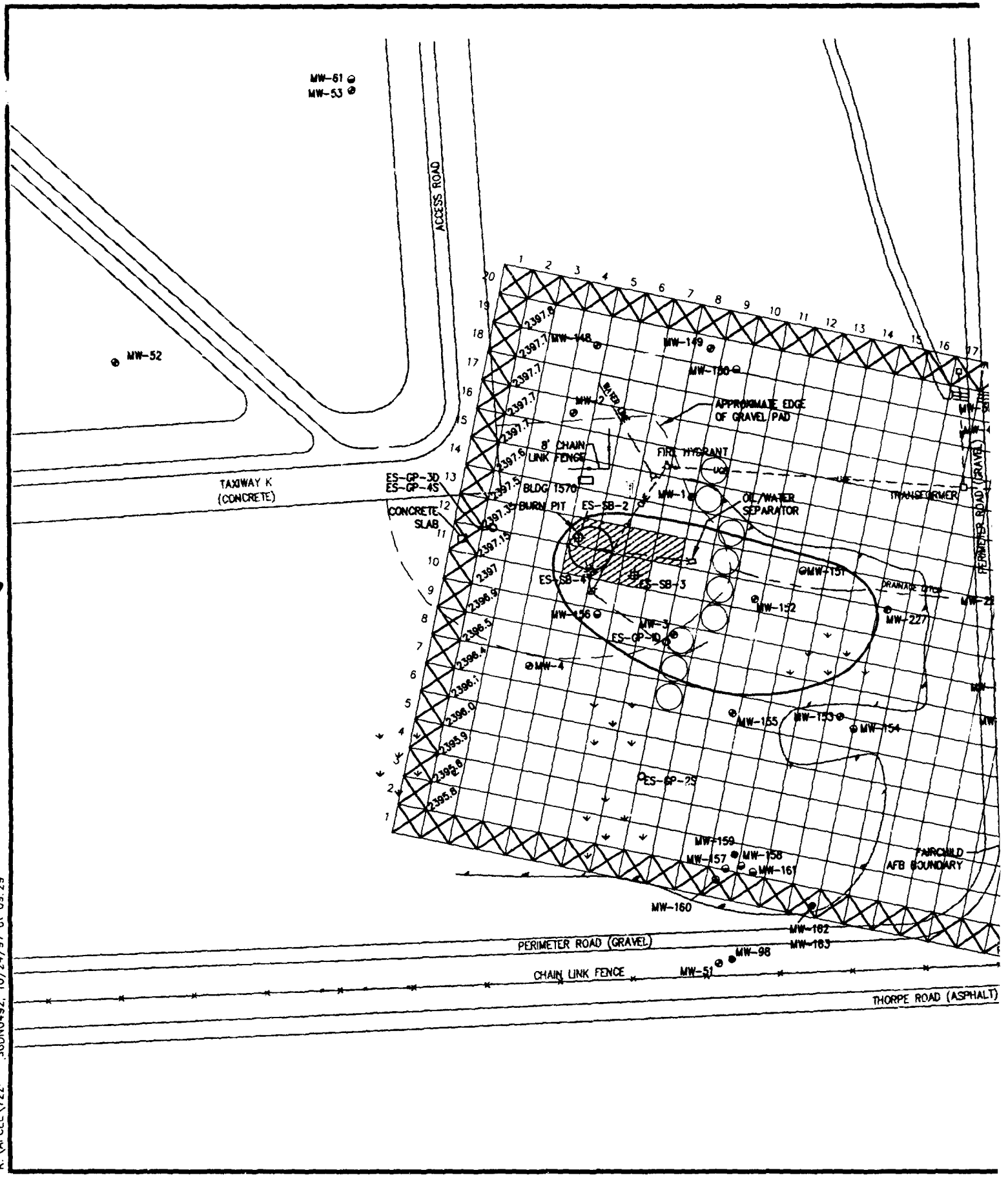
Model boundaries are mathematical statements that represent hydrogeologic boundaries, such as areas of specified head (i.e., surface water bodies or contour lines of constant hydraulic head) or specified flux. Hydrogeologic boundaries are represented by three mathematical statements that describe the hydraulic head at the model boundaries. These include:

- Specified-head boundaries (Dirichlet condition) for which the head is determined as a function of location and time only. Surface water bodies exhibit constant-head conditions. Specified-head boundaries are expressed mathematically as:

$$Head = f(x, y, z, t)$$

  where f is the function symbol, x, y, and z are position coordinates, and t is time.

- Specified-flow boundaries (Neumann conditions) for which the mathematical description of the flux across the boundary is given. The flux is defined as a volumetric flow rate per unit area (i.e., $ft^3/ft^2/day$). No-flow boundaries are a special type of specified-flow boundary and are set by specifying the flux to be zero. Examples of no-flow boundaries include groundwater divides and impermeable hydrostratigraphic units. Specified-flux boundaries are expressed mathematically as:



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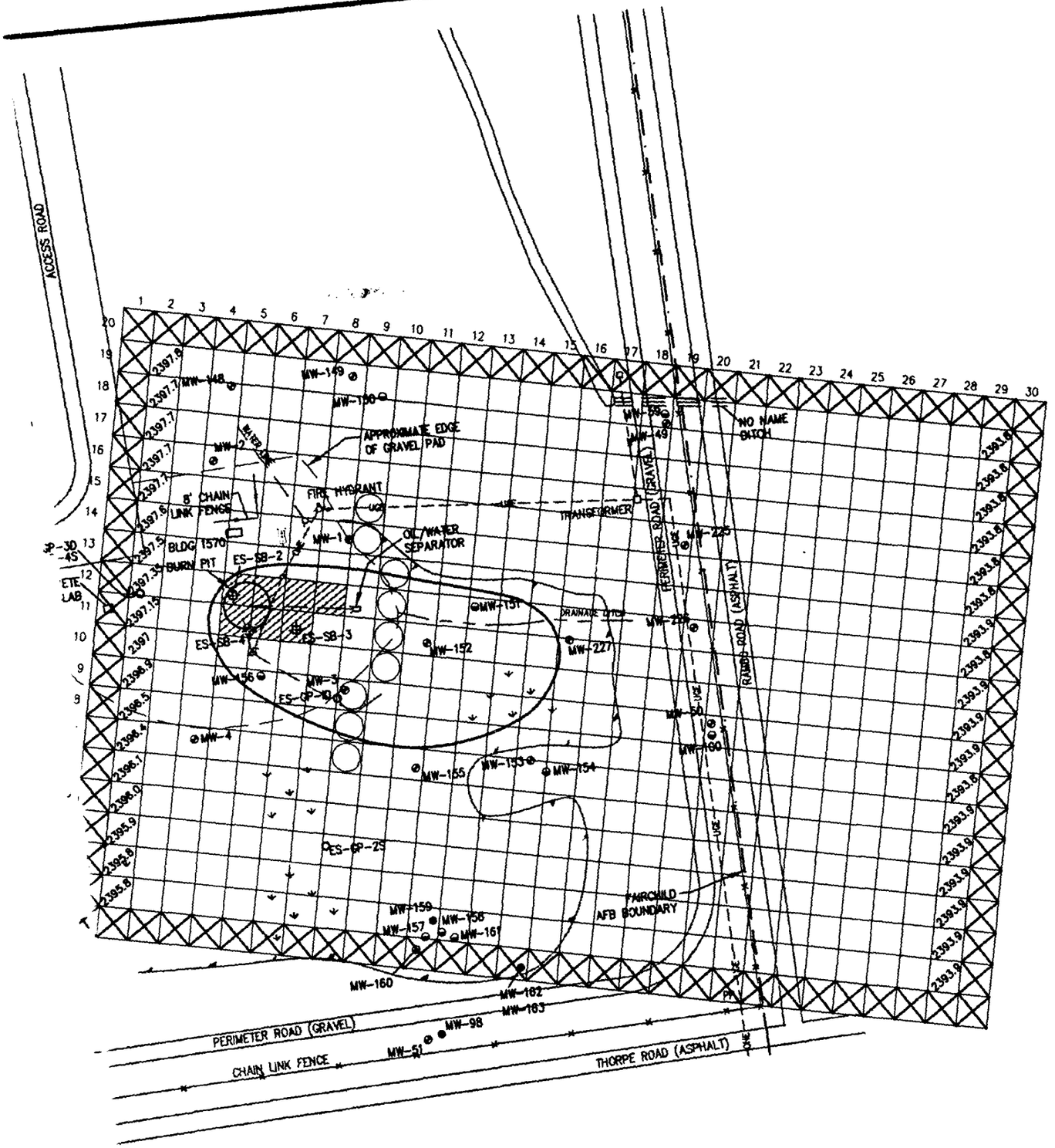
ACCESS ROAD
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
FIRE HYDRANT
TRANSFORMER
OIL/WATER SEPARATOR
BLDG 1570
BURN PIT
ETE LAB
DRAINAGE DITCH
NO NAME DITCH
PERIMETER ROAD (GRAVEL)
RUNWAY ROAD (ASPHALT)
FAIRCHILD AFB BOUNDARY
CHAIN LINK FENCE
THORPE ROAD (ASPHALT)
MW-1
MW-2
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MW-4
MW-48
MW-49
MW-50
MW-51
MW-98
MW-149
MW-150
MW-151
MW-152
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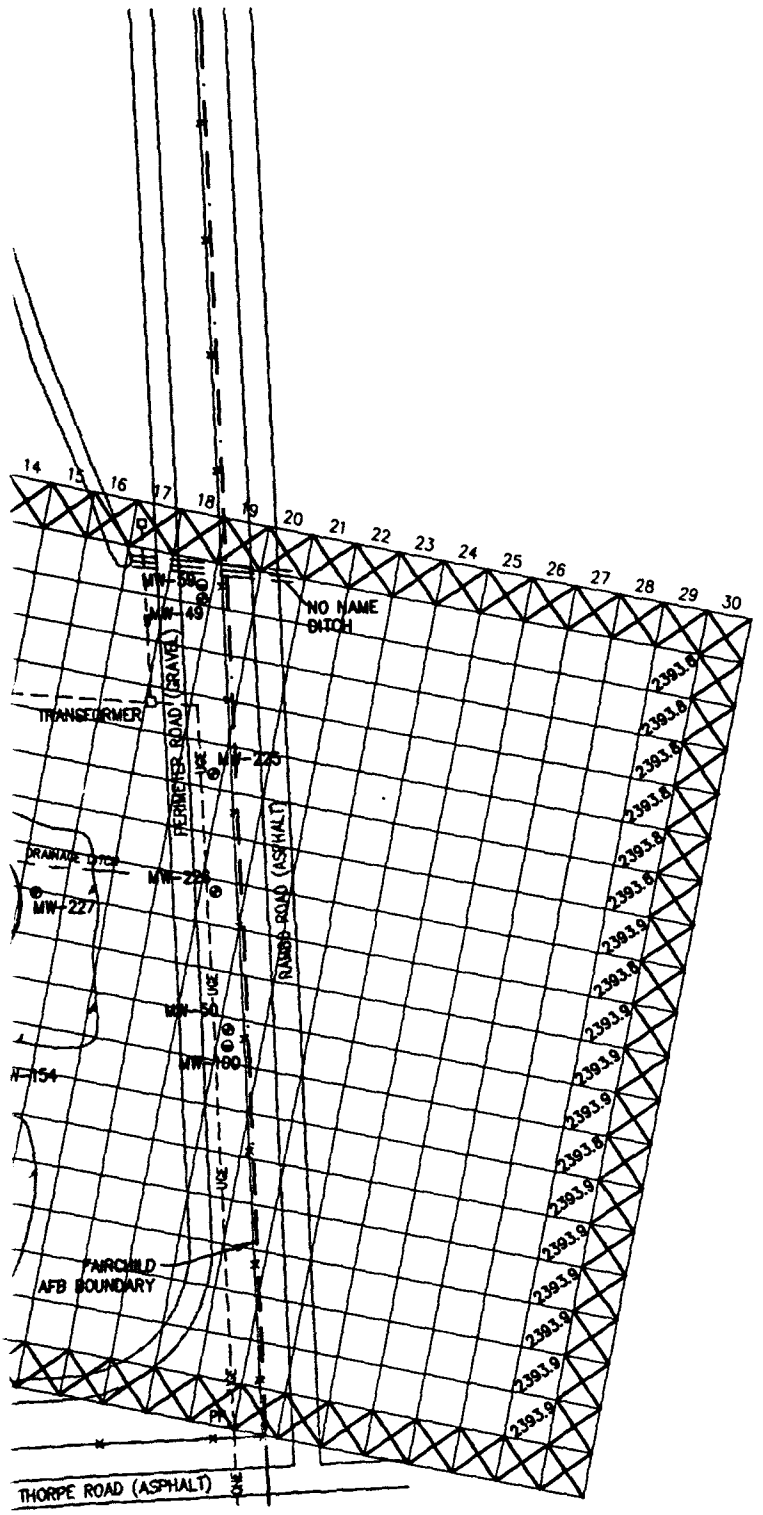
ES-GP-2



LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- TEMPORARY MONITORING POINT
- SOIL SAMPLE LOCATION
- NO FLOW MODEL CELL
- MODEL CELL WITH SIMULATED BTEX INJECTION WELL
- SIMULATED AIR SPARGE WELL
- ESTIMATED EXTENT OF DISSOLVED BTEX PLUME (NOVEMBER 1995)
- CONSTANT HEAD MODEL CELL WITH SIMULATED HEAD VALUE (ft/msl)

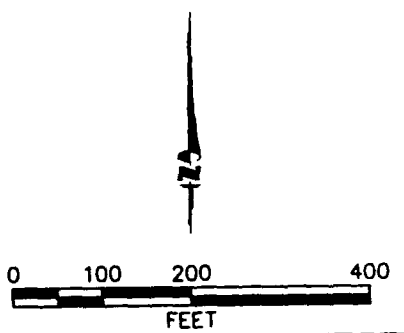


FIGURE 5.1

MODEL GRID

Site FT-1
Remediation By Natural Attenuation TS
Fairchild Air Force Base, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

$$Flux = f(x, y, z, t)$$

- Head-dependent flow boundaries (Cauchy or mixed-boundary conditions) where the flux across the boundary is calculated from a given boundary head value. This type of flow boundary is sometimes referred to as a mixed-boundary condition because it is a combination of a specified-head boundary and a specified-flow boundary. Head-dependent flow boundaries are used to model leakage across semipermeable boundaries. Head-dependent flow boundaries are expressed mathematically as (Bear, 1979):

$$Flux = \frac{(H_0 - H)K'}{B'}$$

Where:

H = Head in the zone being modeled (generally the zone containing the contaminant plume),

H_0 = Head in external zone (separated from plume by semipermeable layer),

K' = Hydraulic conductivity of semipermeable layer, and

B' = Thickness of semipermeable layer.

Natural hydraulic boundaries are modeled using a combination of the three types of model boundary conditions listed above. When possible, hydrologic boundaries such as surface water bodies, groundwater divides, contour lines, or hydrologic barriers should coincide with the perimeter of the model. In areas lacking obvious hydrologic boundaries, specified-head or specified-flux boundaries can be used at the model perimeter if the boundaries are far enough removed from the contaminant plume that transport calculations are not affected. Bioplume II requires the entire model domain to be bounded by zero-flux cells (also known as no-flow cells), with other boundary conditions established within the subdomain specified by the no-flow cells.

As a result of a lack of natural hydrogeologic boundaries and a shifting groundwater flow direction, specified-head boundaries were established on the eastern and western boundaries of the model grid. In two-dimensional models, a row of specified-head boundaries at the up- and downgradient ends of the model grid are typically sufficient to simulate the flow of groundwater for sites that are not hydrogeologically complex or are bounded by adjacent lakes or streams. The head of the western boundary was estimated to be from 2395.8 to 2397.7 feet above msl, and represents the level of groundwater in this portion of the site in November 1995. The heads along the eastern model boundary range from 2393.7 to 2393.9 feet msl.

The base or lower boundary of the model is assumed to be no-flow, and is defined by the upper surface of the basalt bedrock layer located approximately 20 feet bgs. The upper model boundary is defined by the simulated water table surface.

5.3.2 Groundwater Elevation and Gradient

The November 1995 water table elevation map presented in Figure 3.5 was used to define the heads used as initial input into the Bioplume II model. Groundwater flow in the vicinity of FT-1 is to the east-southeast wi[illegible] gradient range over the modeled area of approximately 0.002 ft/ft to 0.008 ft/ft. [illegible]ients are lowest in the downgradient marshy areas and highest near the burn pit.

5.3.3 BTEX Concentrations

As noted in Section 5.2, dissolved BTEX enters groundwater at FT-1 through two ongoing processes: contact between groundwater and residual LNAPL at or below the water table in the source area, and migration of recharge (precipitation) through soil containing residual LNAPL above the water table. The total dissolved BTEX concentrations obtained from laboratory analytical results for each well and monitoring point location were used for model development. At well/point clusters, the BTEX concentration from the shallowest location was selected to represent concentrations in the shallow aquifer. Table 4.3 presents dissolved BTEX concentration data. Figure 4.2 shows the areal distribution of dissolved BTEX compounds in shallow groundwater.

Modeled BTEX dissolution was approximated using simulated [illegible]n wells within seven model cells situated within the core area of soil contaminat[illegible]uding the burn pit and the buried pipe to the oil/water separator (Figure 5.1). Th[illegible] estimated source strength was selected to maintain a mass balance and approximate the observed source area BTEX concentrations. The injection volume for the BTEX injection wells was set at a rate low enough that the hydraulic calibration for the model was not affect[illegible]d.

5.3.4 Dissolved Oxygen

As discussed previously, the Bioplume II model assumes an instantaneous reaction between the BTEX plume and the DO plume. The discussion presented in Section 4 suggests that DO, ferric iron, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for biodegradation of BTEX compounds at the site. To be conservative, the total BTEX plume at the site was modeled assuming that DO was the only electron acceptor being utilized for the biodegradation of the BTEX compounds at a rate that is instantaneous relative to the advective groundwater flow velocity. As described in Section 5.3.5, anaerobic biodegradation, which is not instantaneous relative to the advective groundwater velocity, was accounted for using a first-order rate constant.

Groundwater samples collected in uncontaminated portions of the aquifer indicate that background DO concentrations at the site are as high as 5.7 mg/L (observed at ES-GP-4S). However, in the burn pit (at ES-GPC), DO was less than 1.0 mg/L. As low DO concentrations also were observed downgradient and crossgradient from the burn pit it was assumed that DO is consumed within the source area (Figure 4.3). Therefore, a uniform starting DO concentration of 5.7 mg/L was used for Bioplume II model development. Table 4.5 contains DO data for the site.

The constant-head cells in the Bioplume II model require background DO concentrations to be input as constant concentrations to simulate incoming electron acceptors. A background DO concentration of 5.7 mg/L was used only for the constant-head cells along the upgradient (western) model boundary to simulate a constant influx of uncontaminated oxygenated groundwater.

5.3.5 Biodegradation Rates

Available data strongly suggest that anaerobic degradation is occurring at the site, with combined anaerobic processes accounting for over 94 percent of the BTEX assimilative capacity of site groundwater (Table 4.6). Anaerobic degradation must therefore be simulated with Bioplume II to make meaningful predictions. The Bioplume II model simulates anaerobic biodegradation by assuming that such degradation follows first-order kinetics. As with a large number of biological processes, anaerobic biodegradation can generally be described using a first-order rate constant and the equation:

$$\frac{C}{C_0} = e^{-kt}$$

Where: C = Contaminant Concentration at Time t,

C_0 = Initial Contaminant Concentration,

k = Coefficient of Anaerobic Decay (anaerobic rate constant),

t = time.

Buscheck and Alcantar (1995) derive a relationship that allows calculation of first-order decay rate constants for steady-state plumes. This method involves coupling the regression of contaminant concentration (plotted on a logarithmic scale) versus distance downgradient (plotted on a linear scale) to an analytical solution for one-dimensional, steady-state, contaminant transport that includes advection, dispersion, sorption, and biodegradation (Bear, 1979). For a steady-state plume, the first-order decay rate is given by (Buscheck and Alcantar, 1995):

$$\lambda = \frac{v_c}{4\alpha_x}\left(\left[1 + 2\alpha_x\left(\frac{k}{v_x}\right)\right]^2 - 1\right)$$

Where: λ = first-order decay rate,

v_c = retarded contaminant velocity in the x-direction,

α_x = dispersivity, and

k/v_x = slope of line determined from a log-linear plot of contaminant

concentration versus distance downgradient along flow path.

The first-order decay rate includes biodegradation resulting from both aerobic and anaerobic processes; however, in the absence of oxygen, the first-order rate is equivalent to the anaerobic decay rate. Table 5.1 presents a first-order rate constant calculation for BTEX using a combination of November 1995 and May 1996 data at Site FT-1 and the method proposed by Buscheck and Alcantar (1995). An easterly groundwater flow path through sample locations ES-GPC, MW-152, and MW-227 was used for estimating a biodegradation rate. This flow path represents a groundwater travel path from the anaerobic plume core to the more aerobic downgradient extents. An exponential fit to the data estimates a log-linear slope of 0.016 $feet^{-1}$ which was in turn used to estimate a decay constant of 0.002 day^{-1}. The calculated correlation coefficient of 0.805 demonstrates that the use of a first-order biodegradation rate is acceptable.

A review of recent literature indicates that higher anaerobic rate constants generally have been calculated at other sites. For example, Chapelle (1994) reported that at two different sites with anaerobic groundwater conditions, the anaerobic rate constants were both approximately 0.01 day^{-1}. Wilson *et al.* (1994) reported first-order anaerobic biodegradation rates of 0.05 to 1.3 $week^{-1}$ (0.007 to 0.185 day^{-1}); Buscheck *et al.* (1993) report first-order attenuation rates in a range of 0.001 to 0.01 day^{-1}; and Stauffer *et al.* (1994) report rate constants of 0.01 and 0.018 day^{-1} for benzene and p-xylene, respectively. The anaerobic rate constant of 0.002 day^{-1} used in the Bioplume II model for this site is at the low end of the range reported in the literature. Therefore, this selected biodegradation rate is considered to be conservative.

5.3.6 Dispersivity

Much controversy surrounds the concepts of dispersion and dispersivity. Longitudinal dispersivity values for saturated deposits similar to those found at the site range from 0.1 to 200 feet (Walton, 1988). Longitudinal dispersivity was estimated as 50 feet, using approximately one-tenth (0.1) of the length of the plume from the source area (burn pit) to the downgradient extent of the BTEX plume immediately upgradient of well MW-227 (see Figure 4.3). Transverse dispersivity values generally are estimated as one-tenth (0.1) of the longitudinal dispersivity values (Domenico and Schwartz, 1990).

During plume calibration, longitudinal dispersivity was maintained at 50 feet. This value is moderate compared to possible values given in the literature (Walton, 1988). The use of a lower dispersivity value is a conservative estimate for modeling because low dispersivities cause less BTEX to be lost to dilution. At the same time, the ratio of transverse dispersivity to longitudinal dispersivity was maintained at 0.1 to reproduce the plume width observed at the site.

5.3.7 Coefficient of Retardation

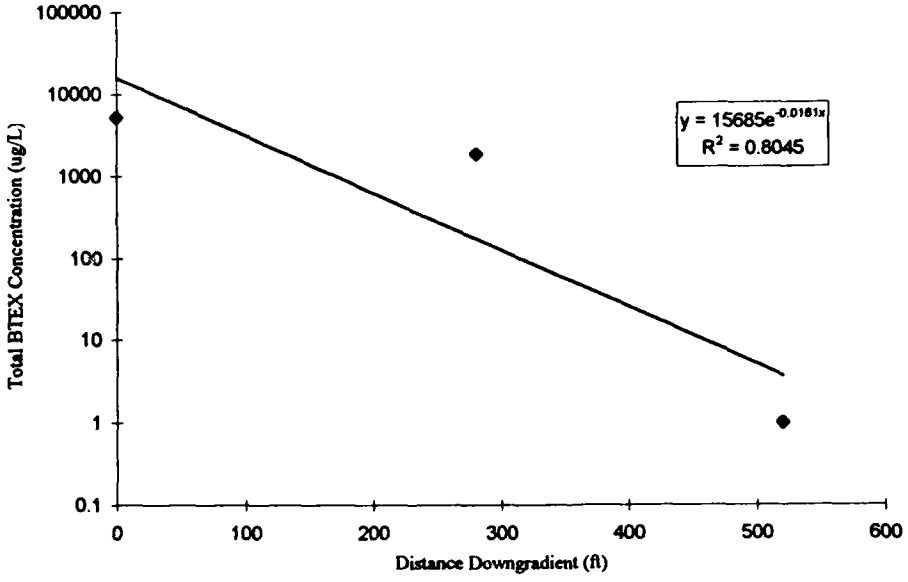
Retardation of the BTEX compounds relative to the advective velocity of the groundwater occurs when BTEX molecules are sorbed to the aquifer matrix. The

TABLE 5.1
FIRST-ORDER RATE CONSTANT CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Point	Distance Downgradient from Source (ft)	Total BTEX (µg/L) Nov-95
ES-GPC[a]	0	5220
MW-152	280	1870
MW-227	520	1

[a] Datum from May 1996 sampling event.

PLOT OF TOTAL BTEX CONCENTRATION VERSUS DISTANCE



$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.063	ft/day
	α_x =	50	ft
	k/v =	0.0161	ft-1
therefore	λ =	0.002	day-1

coefficients of retardation for the BTEX compounds were calculated on the basis of measured TOC concentrations for soils collected in and near the saturated zone at the site, an assumed bulk density of 1.65 grams per cubic centimeter (g/cc) (Domenico and Schwartz, 1990), and published values of the soil sorption coefficients (K_{oc}) for the BTEX compounds, as listed by Wiedemeier *et al.* (1995). The results of these calculations are summarized in Table 5.2.

TOC analyses often are influenced by the presence of soil contamination, which may cause high soil TOC concentrations without necessarily reflecting an increase in the sorptive potential of soil. Therefore, TOC measurements used for retardation estimates should be taken from contaminant-free soils. Furthermore, TOC values should be measured across the water table rather than in the vadose zone to best represent the sorptive potential of saturated soils in the aquifer. Ten locations were chosen for TOC analyses at the FT-1 site (Table 4.1). Of these 10 sampling locations, 4 TOC samples were collected at the target depth outside areas of known contamination and include: ES-SB-1-4', ES-SB-4-4', ES-SB-5-4', and ES-MP-2S-6' (Figure 4.1). All 4 samples were collected near or below the water table and had TOC concentrations ranging from 0.03 to 0.87 percent. Table 5.2 reflects the use of a TOC average for these 4 samples in the calculation of site-specific retardation coefficients. A initial value of 3.19 for the retardation coefficient was used for the BTEX compounds. This is intended to correspond to benzene, which is the COC identified in the ROD, and is the least sorptive BTEX compound. During plume calibration, the initial coefficient of retardation was slightly decreased to achieve a more accurate plume shape. Because, the calibrated value (2.65) is lower than the retardation coefficient calculated from site data, and it is a conservative estimate of BTEX retardation.

5.4 MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site; calibration of a contaminant transport model superimposed upon the calibrated flow model helps verify that contaminant loading and transport conditions are being appropriately simulated. The numerical flow model presented herein was calibrated by altering transmissivity and constant-head boundary conditions in a trial-and-error fashion until simulated heads approximated observed field values within a prescribed accuracy. After calibration of the flow model, the numerical transport model was calibrated by estimating and adjusting the BTEX source loading and transport parameters in a trial-and-error fashion until the simulated BTEX plume approximated observed field values. Table 5.3 lists input parameters used for the modeling effort. Model input and output files are included in Appendix D.

5.4.1 Water Table Calibration

The shallow water table at FT-1 was assumed to be influenced by continuous recharge and discharge at the constant-head cells surrounding the model grid. The initial water levels at the constant-head cells and the transmissivity values were varied

TABLE 5.2
CALCULATION OF RETARDATION COEFFICIENTS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB. WASHINGTON

Compound	K_{oc} (L/kg [a])	Average Fraction Organic Carbon [b]	Distribution Coefficient K_d (L/kg) Average [c]	Bulk Density (kg/L) [d]	Effective Porosity [a]	Coefficient of Retardation Average	Advective Groundwater Velocity (ft/day) [a]	Contaminant Velocity (ft/day)
Benzene	79	0.004	0.33	1.65	0.25	3.19	0.20	0.06
Toluene	190	0.004	0.80	1.65	0.25	6.27	0.20	0.03
Ethylbenzene	468	0.004	1.97	1.65	0.25	14.0	0.20	0.01
m-xylene	405	0.004	1.70	1.65	0.25	12.2	0.20	0 02
o-xylene	422	0.004	1.77	1.65	0.25	12.7	0.20	0.02
p-xylene	357	0.004	1.50	1.65	0.25	10.9	0.20	0.02
							0.20	
TCE	95.1	0.004	0.40	1.65	0.25	3.64	0.20	0.06
cis-1,2-DCE	49	0.004	0.21	1.65	0.25	2.36	0.20	0.08
Vinyl Chloride	2.46	0.004	0.01	1.65	0.25	1.07	0.20	0.19

NOTES:

[a] From technical protocol document (Wiedemeier *et al.*, 1995) and Groundwater Chemical Desk Reference (Mongomery and Welkom, 1990).

[b] From site data (no carbon detected in soil samples from 4-8 ft bgs).

[c] K_d = Average Fraction Organic Carbon x K_{oc}.

[d] Literature values.

TABLE 5.3
BIOPLUME II MODEL INPUT PARAMETERS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Parameter	Description	Calibrated Model Setup	Model FT-1-NA	Model FT-1-BV	Model FT-1-Sparge
NTIM	Maximum number of time steps in a pumping period	10	30	20	20
NPMP	Number of Pumping Periods	7	28	11	11
NX	Number of nodes in the X direction	20	20	20	20
NY	Number of nodes in the Y direction	30	30	30	30
NPMAX	Maximum number of Particles: NPMAX= (NX-2)(NY-2)(NPTPND) + (Ns[a])(NPTPND) + 250	5173	5173	5173	5263
NPNT	Time step interval for printing data	1	1	1	1
NITP	Number of iteration parameters	7	7	7	7
NUMOBS	Number of observation points	0	0	0	0
ITMAX	Maximum allowable number of iterations in ADIP[b]	200	200	200	200
NREC	Number of pumping or injection wells	7	7	7	16
NPTPND	Initial number of particles per node	9	9	9	9
NCODES	Number of node identification codes	1	1	1	1
NPNTMV	Particle movement interval (IMOV)	0	0	0	0
NPNTVL	Option for printing computed velocities	1	1	1	1
NPNTD	Option to print computed dispersion equation coefficients	1	1	1	1
NPDELC	Option to print computed changes in concentration	1	1	1	1
NPNCHV	Option to punch velocity data	0	0	0	0
NREACT	Option for biodegradation, retardation and decay	1	1	1	1
PINT	Pumping period (years)	25	75	48	48
TOL	Convergence criteria in ADIP	0.001	0.001	0.001	0.001
POROS	Effective porosity	0.25	0.25	0.25	0.25
BETA	Characteristic length (long. dispersivity; feet)	50	50	50	50
S	Storage Coefficient	0 (Steady-State)	0 (Steady-State)	0 (Steady-State)	0 (Steady-State)
TIMX	Time increment multiplier for transient flow	-	-	-	-
TINIT	Size of initial time step (seconds)	-	-	-	-
XDEL	Width of finite difference cell in the x direction (feet)	50	50	50	50
YDEL	Width of finite difference cell in the y direction (feet)	50	50	50	50
DLTRAT	Ratio of transverse to longitudinal dispersivity	0.1	0.1	0.1	0.1
CELDIS	Maximum cell distance per particle move	0.5	0.5	0.5	0.5
ANFCTR	Ratio of Tyy to Txx (1 = isotropic)	1	1	1	1
DK	Distribution coefficient	0.25	0.25	0.25	0.25
RHOB	Bulk density of the solid (grams/cubic centimeter)	1.65	1.65	1.65	1.65
THALF	Half-life of the solute	-	-	-	-
DEC1	Anaerobic decay coefficient (day^{-1})	0.001	0.001	0.001	0.001
DEC2	Reaeration coefficient (day^{-1})	0.0	0.0	0.0	0.0
F	Stoichiometric Ratio of Hydrocarbons to Oxygen	3.14	3.14	3.14	3.14

[a] Ns = Number of nodes that represent fluid sources (wells or constant head cells).

[b] ADIP = Alternating-direction implicit procedure (subroutine for solving groundwater flow equation).

to calibrate the water table surface. The model was calibrated under steady-state conditions.

Hydraulic conductivity is an important aquifer characteristic that determines the ability of the water-bearing strata to transmit groundwater. Transmissivity is the product of the hydraulic conductivity and the thickness of the aquifer. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer and the quantity of electron-acceptor-charged groundwater that is entering the site from upgradient locations. According to the work of Rifai *et al.* (1988), the Bioplume II model is particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume with a relatively small areal extent and a higher average BTEX concentration. Higher values of hydraulic conductivity result in a faster-moving plume that is spread over a larger area and contains lower average BTEX concentrations.

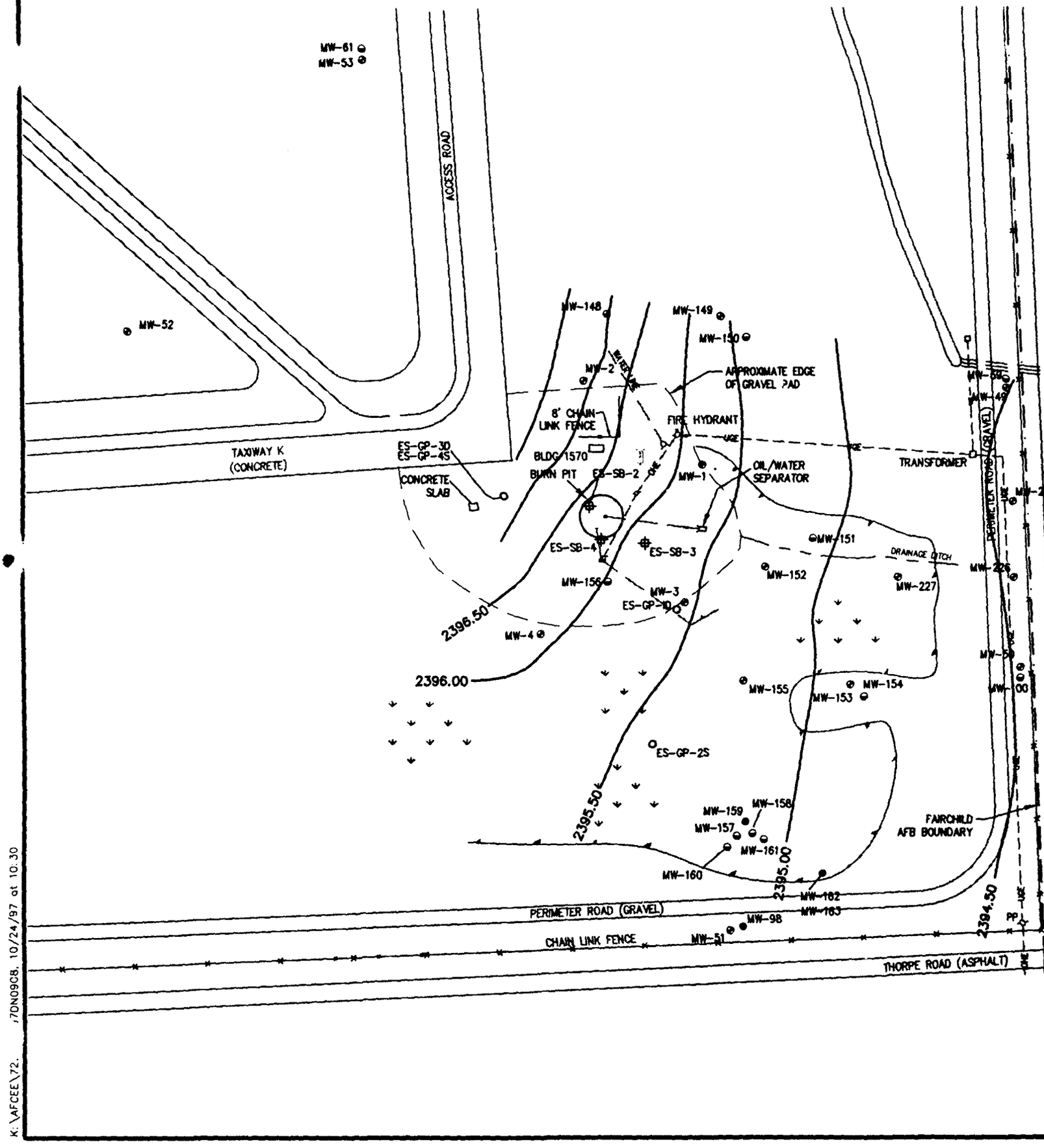
Saturated thickness data from previous reports, geologic logs, and water level measurements were used in conjunction with the hydraulic conductivity estimates to create an initial transmissivity grid for the entire model. To better match heads in the model to observed values, the transmissivities were progressively varied in blocks and rows until the simulated water levels for cells corresponding to selected well locations matched the observed water levels as closely as possible. Figure 5.2 shows the calibrated water table.

Calibrated model hydraulic conductivities ranged from 7.0×10^{-4} foot per second (ft/sec) to 1.2×10^{-5} ft/sec (60.5 ft/day to 0.2 ft/day). Hydraulic conductivities were varied through this wide range of values to help achieve a reasonable representation of the observed groundwater table at the site.

A precipitation recharge rate of 2.5 inches per year was assumed to enter the aquifer across the entire site. This is equivalent to approximately 10 percent of the annual precipitation at Fairchild ARB. Although this rate may be low because of the lack of vegetation on the gravel pad, it is considered to acceptable due to the leakage of shallow groundwater into the shallow bedrock. Because Bioplume is a 2-D groundwater model and does not have vertical aquifer leakage parameters, modeled groundwater recharge was assumed to be equal to the difference between recharge due to precipitation and loss due to aquifer leakage.

Water level elevation data from cells associated with 12 groundwater monitoring locations were used to compare measured and simulated heads for calibration. The 12 selected cell locations each contained one of the following shallow monitoring wells: MW-1, MW-3, MW-4, MW-49, MW-50, MW-148, MW-152, MW-153, MW-155, MW-225, MW-226, and MW-227.

The root mean square (RMS) error is commonly used to express the average difference between simulated and measured heads. RMS error is the average of the squared differences between measured and simulated heads, and can be expressed as:



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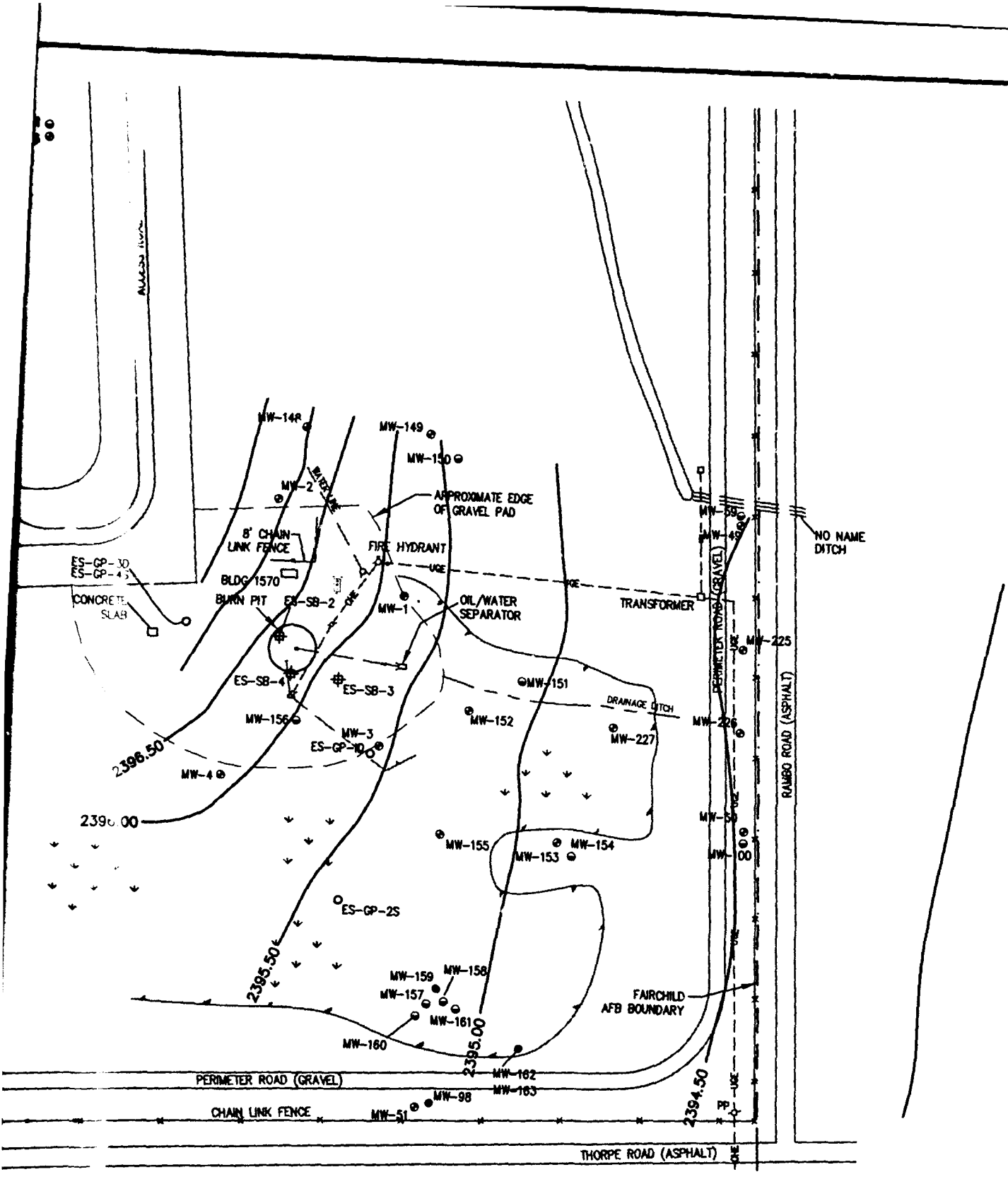
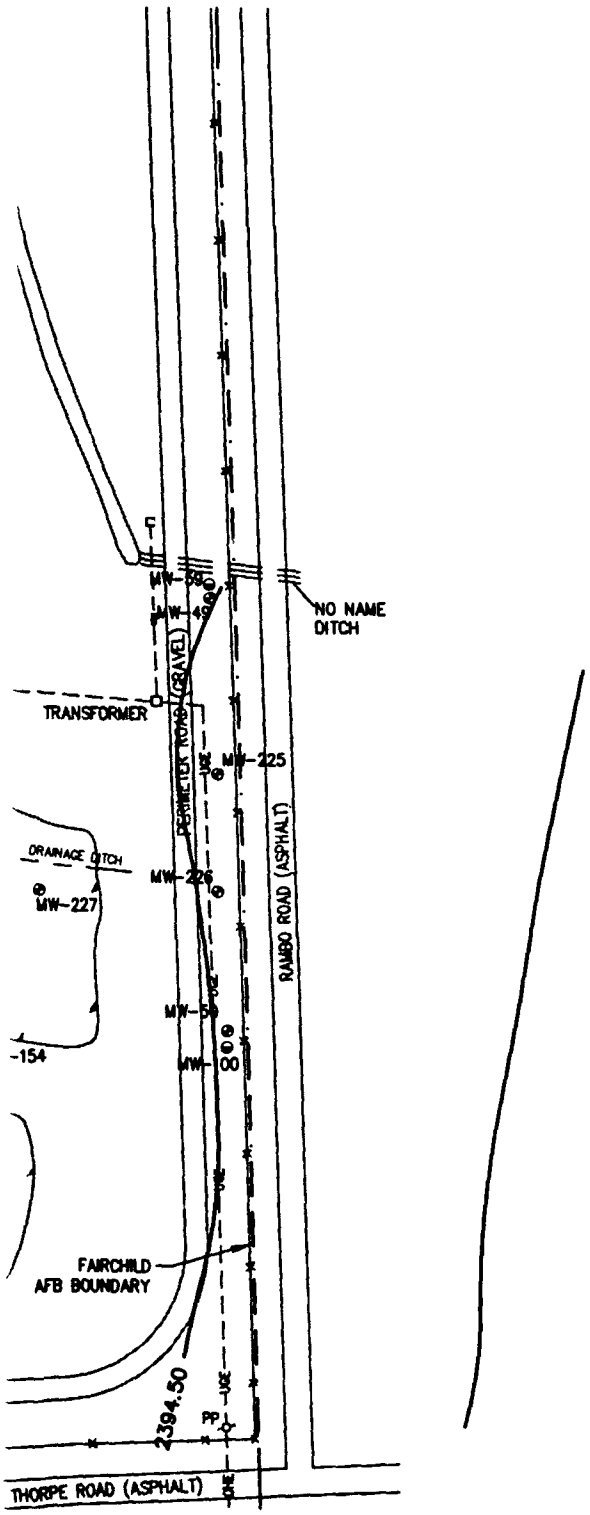

MW-14R
MW-149
MW-150
MW-2
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
FIRE HYDRANT
BLDG 1570
BURN PIT
ES-SB-2
MW-1
OIL/WATER SEPARATOR
CONCRETE SLAB
TRANSFORMER
MW-58
MW-49
NO NAME DITCH
PERIMETER ROAD (GRAVEL)
MW-225
RAMBO ROAD (ASPHALT)
ES-SB-4
ES-SB-3
MW-151
DRAINAGE DITCH
MW-156
MW-152
MW-226
MW-227
MW-3
ES-GP-1D
2396.50
MW-4
2396.00
MW-155
MW-154
MW-153
MW-00
ES-GP-2S
2395.50
MW-159
MW-158
MW-157
MW-161
FAIRCHILD AFB BOUNDARY
MW-160
2395.00
MW-162
MW-163
PERIMETER ROAD (GRAVEL)
MW-98
CHAIN LINK FENCE
MW-51
2394.50
PP
THORPE ROAD (ASPHALT)



LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- TEMPORARY MONITORING POINT
- SOIL SAMPLE LOCATION
- 2395.00 — LINE OF EQUAL SIMULATED GROUNDWATER ELEVATION (FT ABOVE MEAN SEA LEVEL)

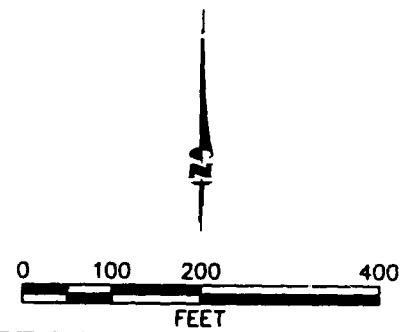


FIGURE 5.2

CALIBRATED WATER TABLE

Site FT-1
Remediation By Natural Attenuation TS
Fairchild Air Force Base, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

$$RMS = \left[\frac{1}{n} \sum_{i=1}^{n} (h_m - h_s)_i^2 \right]^{0.5}$$

Where: n = the number of points where heads are being compared,

h_m = measured head value (feet above msl), and

h_s = simulated head value (feet above msl).

The RMS error between observed and calibrated values at the 126 comparison points was 0.16 feet, which corresponds to a calibration error of 4.0 percent (water levels dropped 4.0 feet over the length of the model grid). RMS error calculations are summarized in Appendix C. A plot of measured versus calibrated heads shows a random distribution of points around a straight line, as shown in Appendix C. Deviation of pointsfrom a straight line should be randomly distributed in such a plot of results from computer simulations (Anderson and Woessner, 1992).

In solving the groundwater flow equation, Bioplume II establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. Considering the groundwater hydraulics at the site, the hydraulic mass balance for the calibrated model was reasonable, with 99.94 percent of the water flux into and out of the system being numerically accounted for (i.e., a 0.06-percent error). According to Anderson and Woessner (1992), a mass balance error of around 1 percent is acceptable, while Konikow (1978) indicates an error of less than 0.1 percent is ideal.

5.4.2 BTEX Plume Calibration

Model input parameters affecting the distribution and concentration of the simulated BTEX plume were modified so that model predictions matched dissolved total BTEX concentrations observed in November 1995. The groundwater sample collected from ES-GPC within the burn pit in May 1996 was assumed to be comparable to November 1995 concentrations. BTEX plume calibration model runs were made using the calibrated steady-state hydraulic parameters coupled with the introduction of contaminants. Because the exact time and frequency of the waste fuel releases at the site are unknown, the model was calibrated to match November 1995 conditions, assuming the groundwater was first impacted 25 years ago, with fire training exercises continuing at regular intervals until about 5 years ago. Seven leaching periods were used in the calibration to simulate different source areas and rates prior to 1995.

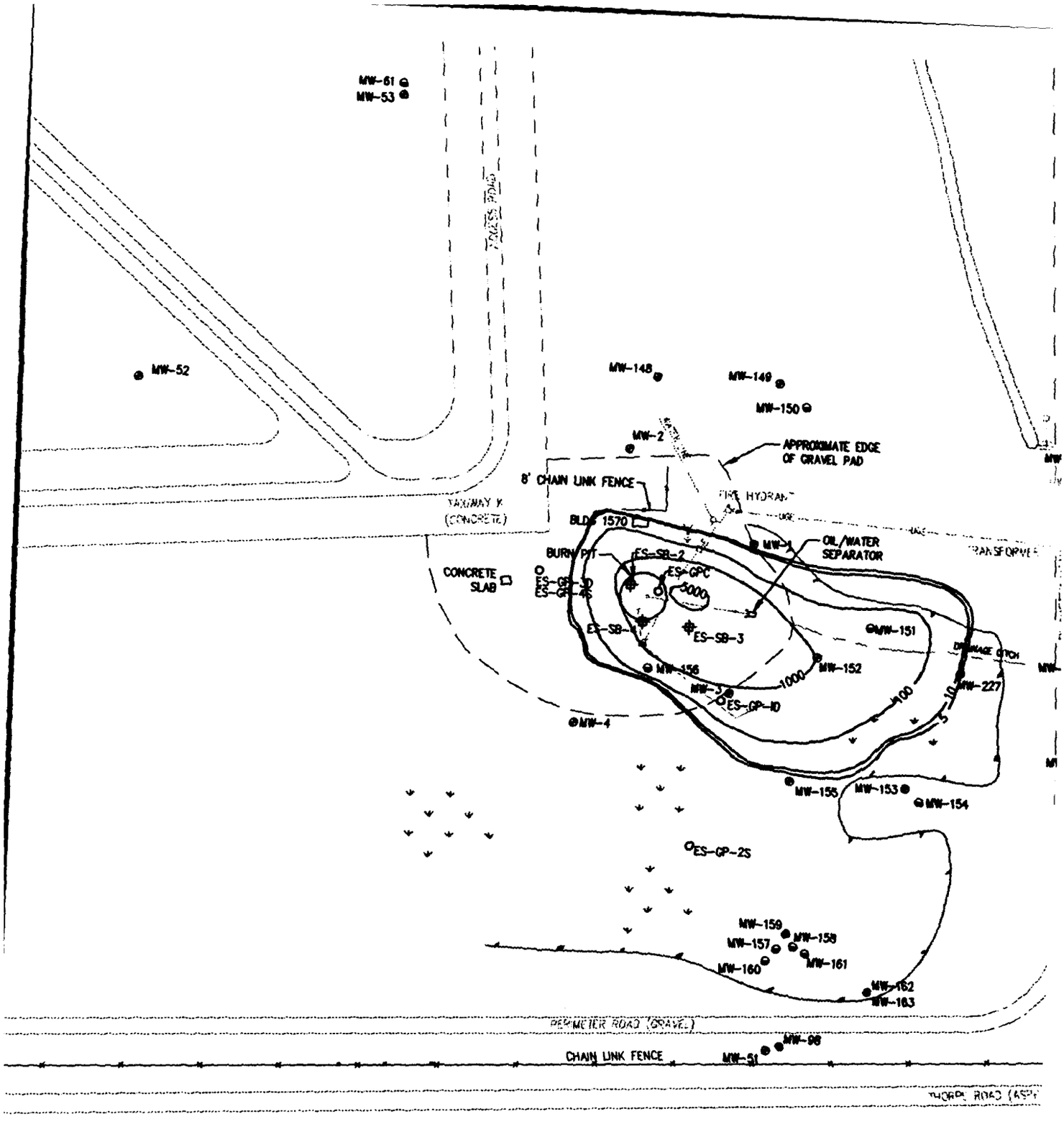
Estimated BTEX source concentrations (Section 5.3.3) were applied to seven of the simulated injection wells of the model grid to reproduce the configuration and concentrations of the groundwater BTEX plume (Figure 5.1). While the term "injection well" suggests contaminants are being introduced at a point, Bioplume II assumes that contamination introduced at a well instantly equilibrates throughout the entire cell in which the well is located. The injection rate for the cells was 1.2×10^{-5} cubic foot per second (ft^3/sec) and is low enough that the flow calibration and water

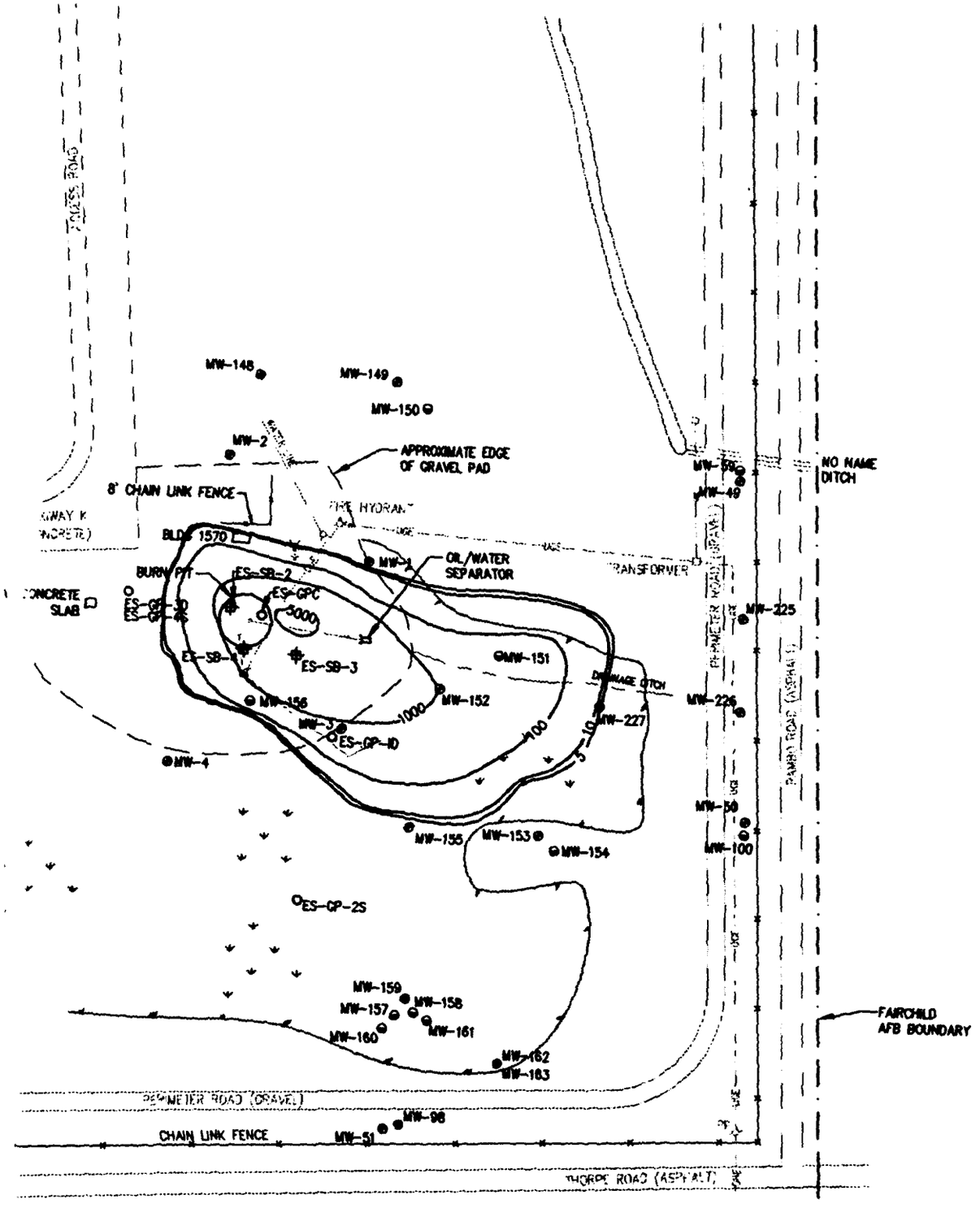
balance were not affected. Loading rates and periods were varied cell by cell as needed to reproduce the shape of the observed groundwater plume. In this manner, the potential source strength of the residual contamination was maintained while simultaneously obtaining the configuration of the observed BTEX plume (Figure 4.3).

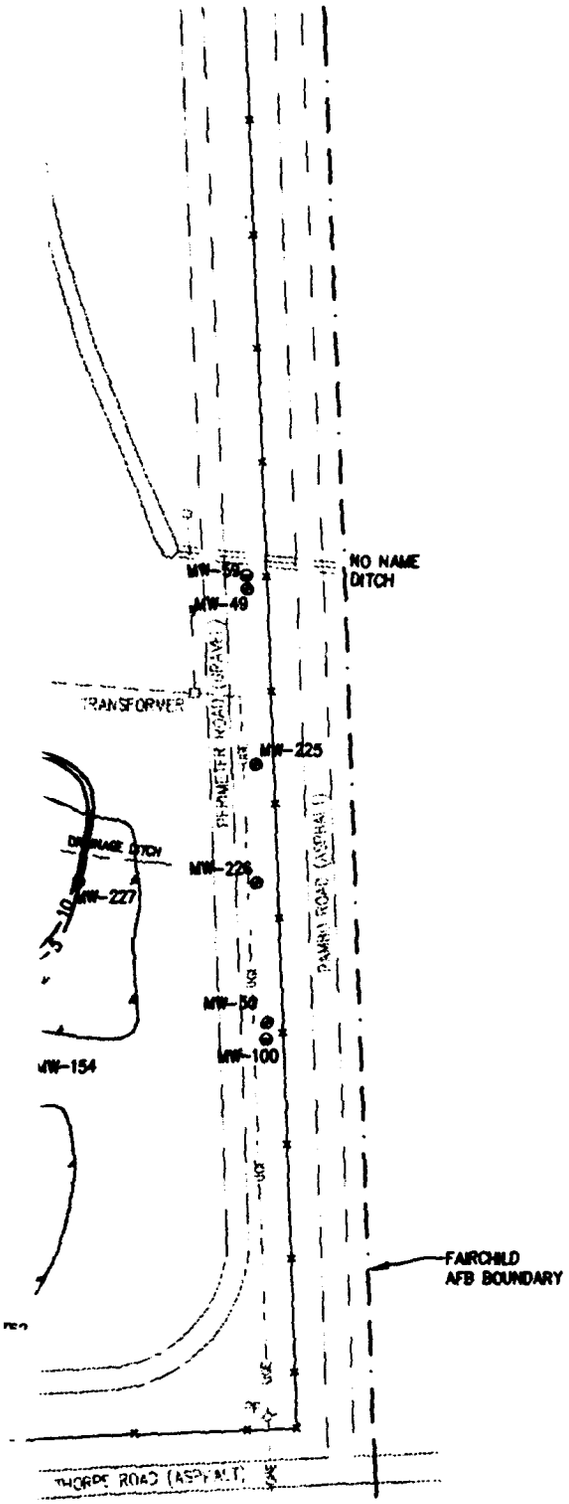
Seven leaching periods were used to model the configuration of the BTEX plume beneath the former fire training area. For the first 10 years (1971-1980), moderate amounts of BTEX were injected at 6 injection wells. This represents the assumed start of fire training activities and the buildup of a residual fuel source. For model years 11 to 20 (1981-1990), both the BTEX injection rates and the number of injection wells were increased. These increases were justified because the volume of fuel stored in the soil and the extent of the impacted area are expected to have increased with the continued fire training activities and use of the oil/water separator east of the burn pit. In 1991, fire training exercises ceased, and the use of the oil/water separator discontinued. From 1991 to 1993, the BTEX loading rates at the seven injection cells were decreased at 5 percent per year to account for natural decay processes (e.g., volatilization, dissolution, or biodegradation) occurring at the inactive fire training area. The final 2 years of the model calibration (1994-1995) consisted of 50-percent annual source decay at all injection wells due to the bioventing pilot study conducted in the burn pit. Soil samples collected before the bioventing had BTEX concentrations ranging from 600 to 1900 µg/kg. At the conclusion of the bioventing pilot test, six confirmatory soil samples collected in approximately the same location did not have any BTEX compounds detected (Parsons ES, 1996). The calibrated dissolved BTEX plume is shown in Figure 5.3. The final calibrated model plume (year 25) was assumed to represent present-day (1996) conditions and compares favorably to the observed BTEX plume (Figure 5.1).

The objective of the calibration was to achieve a modeled plume that equaled or exceeded the observed plume in terms of extent and concentration, and that effectively simulated the flow of BTEX contaminants from the source areas to the observed downgradient locations. The calibrated model successfully meets these objectives, as it reproduces both the observed areal extent and contaminant concentrations. The calibrated plume accurately predicts a flow of contamination from the source area toward the east. In the vicinity of ES-GPC, simulated BTEX concentrations are within 7 percent of the observed concentrations. However, because the model simulates the injection concentration over the entire cell, the calibrated contours extend further upgradient from the burn pit than indicated by site data. The 1,000-µg/L contour approximated from observed site conditions stretches from the center of the burn pit and ends near monitoring wells MW-3 and MW-152. The downgradient extent of the modeled 5-µg/L contour correlates with the observed conditions.

The fact that the model concentrations in the source area are slightly higher than observed concentrations means that additional BTEX mass is accounted for in the model simulations and that model predictions are conservative. Variations in shape between the model and the observed plume likely are due to subsurface heterogeneities in the hydraulic conductivity, anaerobic decay, dispersivity, and retardation that are


MW-61
MW-53
MW-52
MW-148
MW-149
MW-150
MW-2
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
TAXIWAY K (CONCRETE)
BLDG 1570
FIRE HYDRANT
MW-1
OIL/WATER SEPARATOR
BURN PIT
ES-SB-2
ES-GP-3D
ES-GP-2S
CONCRETE SLAB
5000
ES-SB-1
ES-SB-3
MW-151
DRAINAGE DITCH
MW-156
MW-152
1000
MW-3
ES-GP-1D
MW-227
100
10
5
MW-4
MW-155
MW-153
MW-154
ES-GP-2S
MW-159
MW-158
MW-157
MW-161
MW-160
MW-162
MW-163
PERIMETER ROAD (GRAVEL)
MW-98
CHAIN LINK FENCE
MW-51


MW-148
MW-149
MW-150
MW-2
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
FIRE HYDRANT
BLDG 1570
BURN PIT
ES-SB-2
ES-GPC
5000
OIL/WATER SEPARATOR
TRANSFORMER
CONCRETE SLAB
ES-SB-3
MW-151
DRAINAGE DITCH
MW-156
MW-152
1000
100
5-10
MW-227
MW-3
ES-GP-ID
MW-4
MW-155
MW-153
MW-154
ES-GP-2S
MW-159
MW-157
MW-158
MW-160
MW-161
MW-162
MW-163
PERIMETER ROAD (GRAVEL)
MW-98
CHAIN LINK FENCE
MW-51
THORPE ROAD (ASPHALT)
MW-58
MW-49
NO NAME DITCH
PERIMETER ROAD (ASPHALT)
MW-225
MW-226
MW-50
MW-100
FAIRCHILD AFB BOUNDARY



LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- TEMPORARY MONITORING POINT
- SOIL SAMPLE LOCATION
- —10— LINES OF EQUAL BTEX CONCENTRATION IN µg/L

0 100 200 400

FEET

FIGURE 5.3

CALIBRATED BTEX PLUME

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

extremely difficult to identify in the field and to replicate in a discretized 2-D model domain.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. According to the work of Rifai *et al.* (1988), the Bioplume II model is most sensitive to changes in the coefficient of aerobic decay (reaeration coefficient), the coefficient of anaerobic decay, and the hydraulic conductivity of the media, and is less sensitive to changes in the retardation factor, porosity, and dispersivity. To fully evaluate the sensitivity of the calibrated model, the transmissivity, the coefficient of anaerobic decay, the coefficient of retardation, dispersivity, and porosity were all varied. The reaeration coefficient was not used in this model.

To perform the sensitivity analyses, the aforementioned parameters were individually and systematically varied; the model was rerun, and the results were compared to the original calibrated model. Each sensitivity model was run for a 25-year period (the same duration used in the original calibrated model) to assess the independent effect of each variable. A total of 10 sensitivity runs of the calibrated model were performed, with the following variations:

1) Transmissivity uniformly increased by a factor of 5;

2) Transmissivity uniformly decreased by a factor of 5;

3) Coefficient of anaerobic decay increased by a factor of 2;

4) Coefficient of anaerobic decay decreased by a factor of 2;

5) Coefficient of retardation increased by 20 percent;

6) Coefficient of retardation decreased by 20 percent;

7) Dispersivity increased by 50 percent;

8) Dispersivity decreased by 50 percent;

9) Porosity increased by 25 percent; and

10) Porosity decreased by 25 percent.

The results of the sensitivity analyses are shown graphically in Figures 5.4 through 5.8. These figures display simulated BTEX concentrations versus distance downgradient from the source area. This manner of displaying data is useful because changes in BTEX concentrations can be easily visualized.

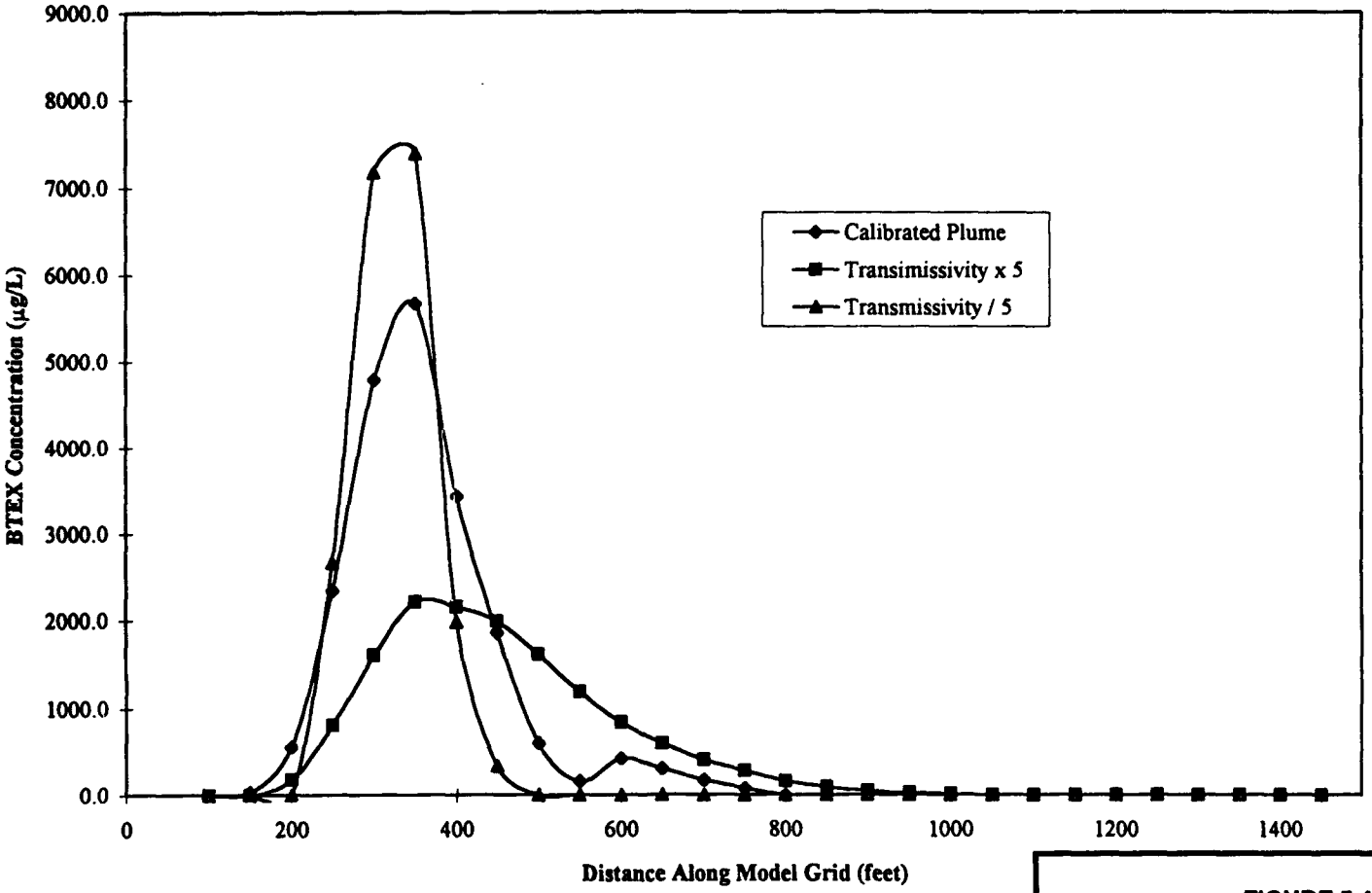
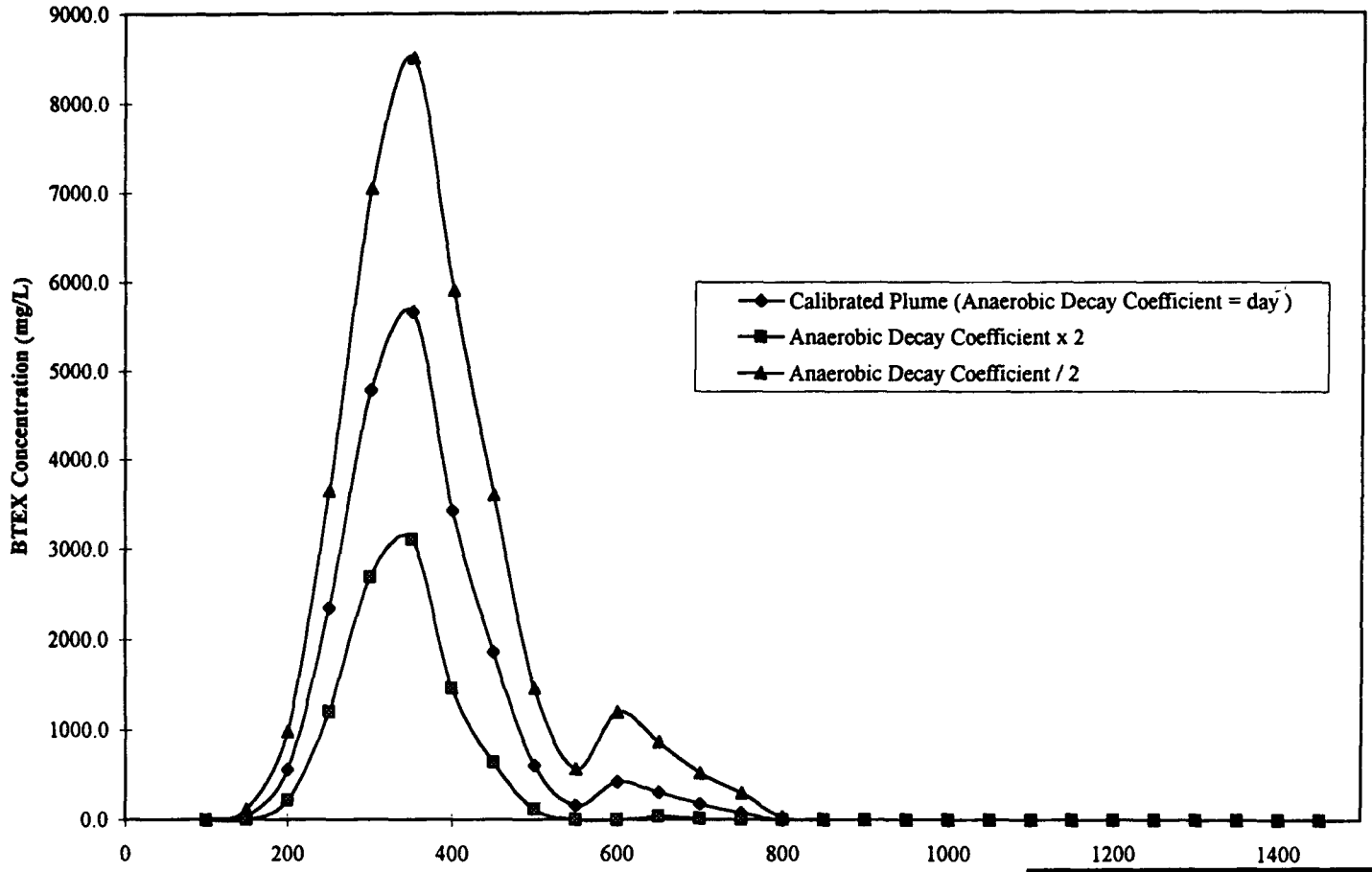


FIGURE 5.4

MODEL SENSITIVITY TO VARIATIONS IN TRANSMISSIVITY

Site FT-1
Remediation by Natural Attenuation
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



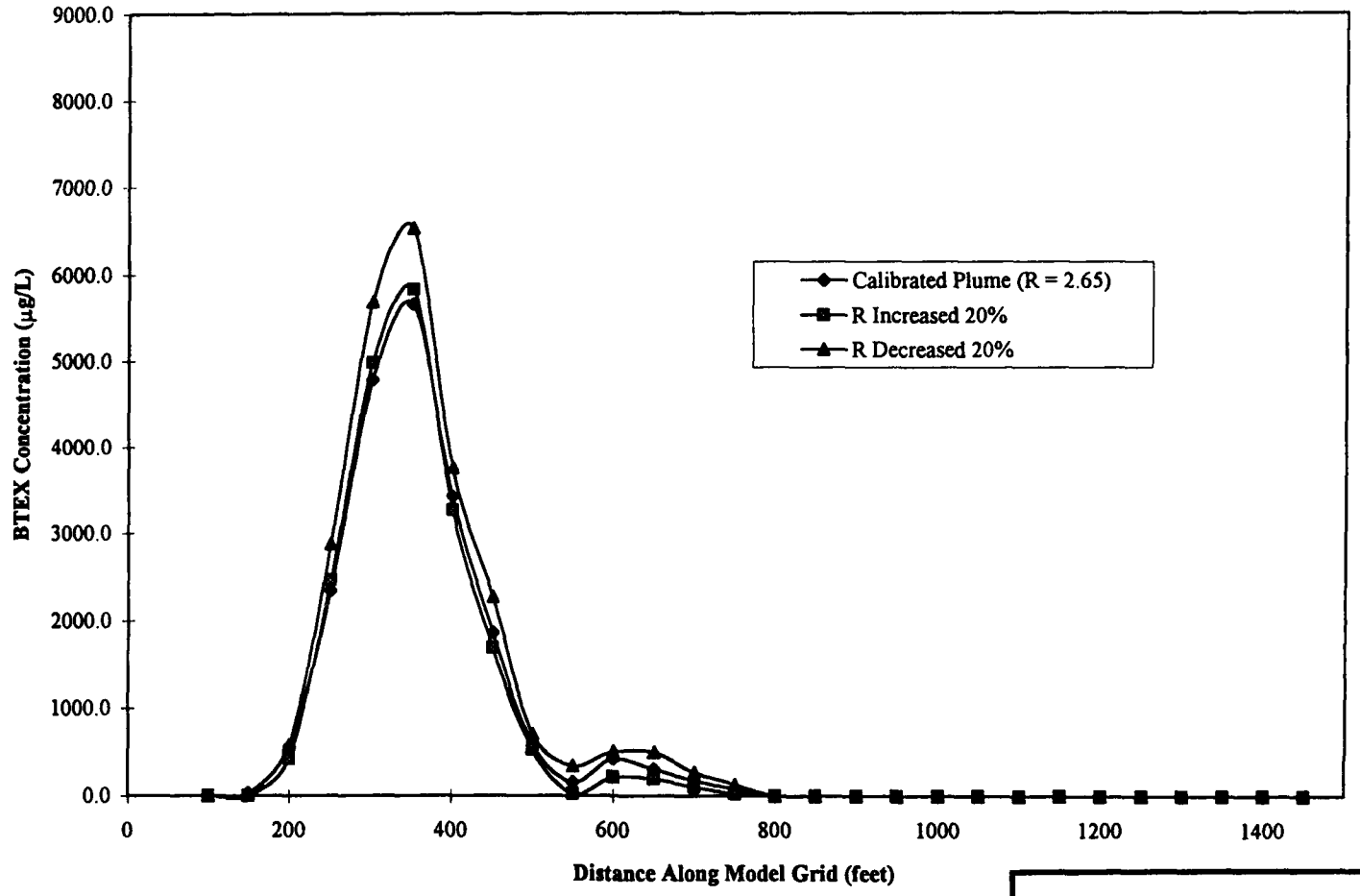
Source: ICF Technology Inc., 1995.

FIGURE 5.5

MODEL SENSITIVITY TO VARIATIONS IN THE ANAEROBIC DECAY COEFFICIENT

Site FT-1
Remediation by Natural Attenuation
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



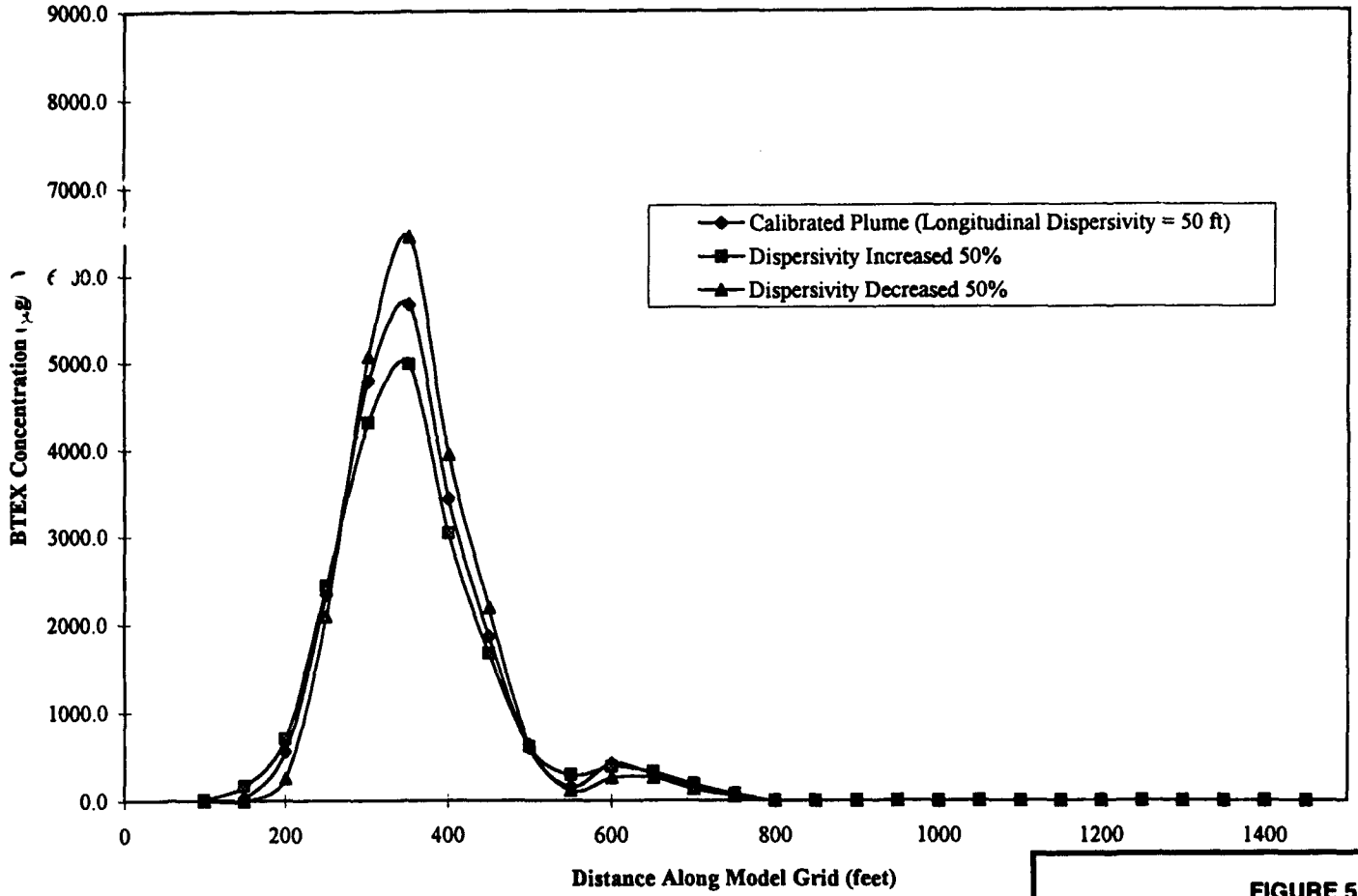
Source: ICF Technology Inc., 1995.

FIGURE 5.6

MODEL SENSITIVITY TO VARIATIONS IN THE COEFFICIENT OF RETARDATION

Site FT-1
Remediation by Natural Attenuation
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



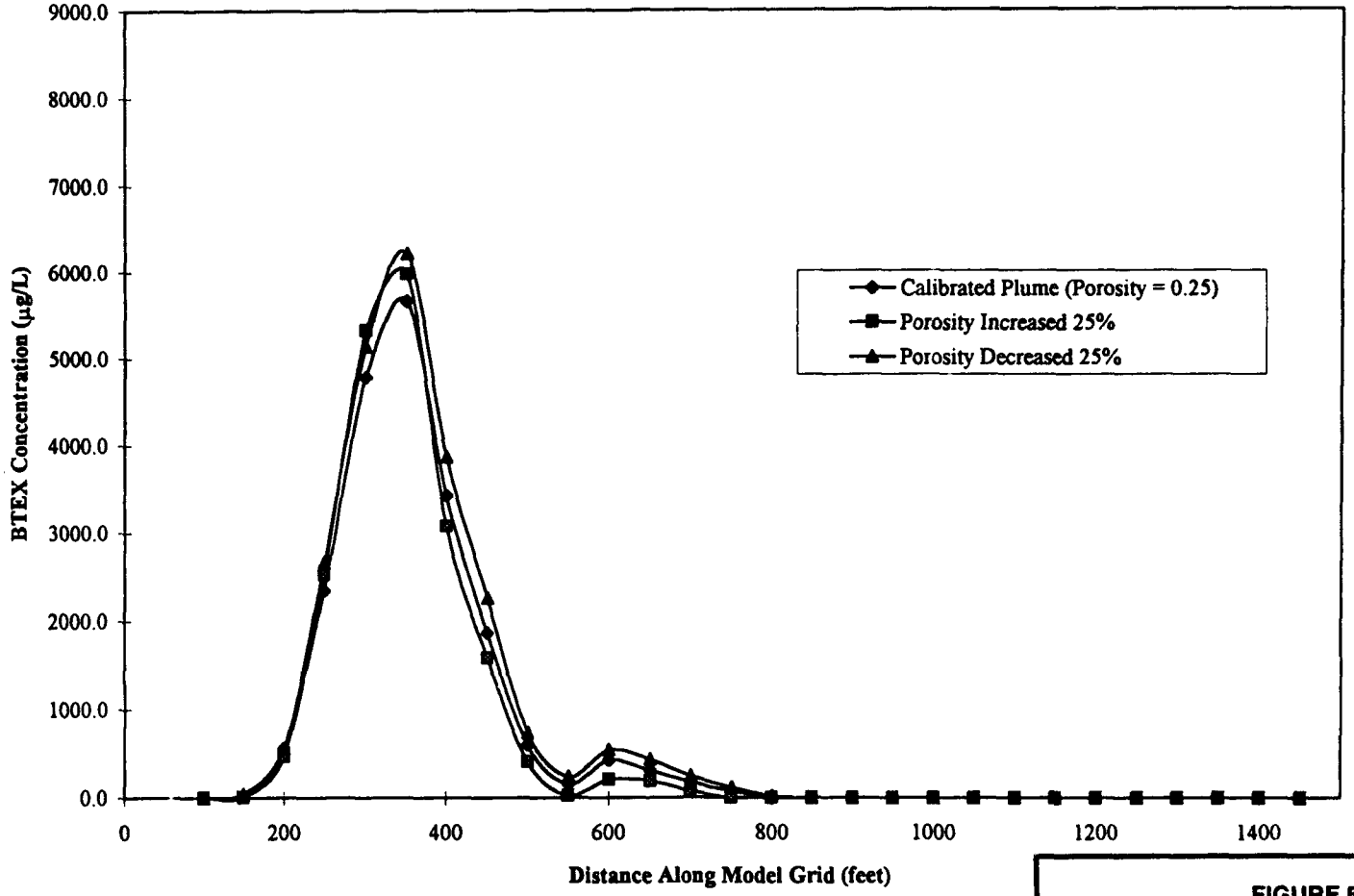
Source: ICF Technology Inc., 1995.

FIGURE 5.7

MODEL SENSITIVITY TO VARIATIONS IN DISPERSIVITY

Site FT-1
Remediation by Natural Attenuation
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



Source: ICF Technology Inc., 1995.

FIGURE 5.8

MODEL SENSITIVITY TO VARIATIONS IN POROSITY

Site FT-1
Remediation by Natural Attenuation
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

The effects of varying transmissivity are shown on Figure 5.4. Uniformly increasing the transmissivity by a factor of five increased groundwater velocity, and therefore decreased the residence time of groundwater in the aquifer. As a result, BTEX concentrations decreased throughout the plume because of increased dilution of the BTEX compounds. However. the plume is also much longer. BTEX concentrations at the head of the plume degraded faster because of the influx of electron acceptors from upgradient sources, but the downgradient portion of the plume migrates further and faster, due to the increased velocity. Under this scenario for transmissivity, the maximum observed BTEX concentration in the source area was 2,210 µg/L, compared to the calibrated 5,660 µg/L. In contrast, decreasing the transmissivity by a factor of five slowed overall plume migration, which increased the maximum BTEX concentrations because of decreased dilution and spreading. The BTEX concentration in the source area increased to approximately 7,385 µg/L, and the BTEX contamination did not extend downgradient from source area. The sensitivity of the model to hydraulic conductivity suggests that appropriate transmissivity values were used in the model calibration.

The effects of varying the coefficient of anaerobic decay are illustrated by Figure 5.5. As expected, increasing this parameter by a factor of two results in a smaller plume with a maximum BTEX concentration of only 3,100 µg/L. In addition, the BTEX plume is approximately 100 feet shorter. Conversely, decreasing the coefficient of anaerobic decay by a factor of two decreases the biodegradation rate and increases plume concentrations. The resultant increase raised computed maximum BTEX concentrations in the source area from 5,660 µg/L to 8,510 µg/L. These results show that the calibrated model is sensitive to variations in the coefficient of anaerobic decay and suggest that the coefficient of anaerobic decay calculated by the method of Buscheck and Alcantar (1995) is a reasonable value for the calibrated model.

The effects of varying the coefficient of retardation (R) are shown on Figure 5.6. Increasing R by 20 percent has a minor effect on the contaminant distribution. An increase in sorptive capacity caused a slight increase of approximately 170 µg/L in the source area, producing a maximum BTEX concentration at 5,830 µg/L. The slight increase in the maximum plume concentration resulted from a slowing of BTEX migration, which allowed for greater BTEX accumulation in the source area. A slight decrease in downgradient concentrations resulted from an increased contact period of the sorbed BTEX with electron flushing into the system. Decreasing R by 20 percent decreases the potential for contact of sorbed BTEX with replenished electron acceptors, thus allowing less biodegradation. As a result, the maximum BTEX concentration in the source area increased to 6,220 µg/L, without a noticeable change in the downgradient BTEX extent. Because the retardation factor used for the model is lower relative to the calculated value (Table 5.3), the R used for the calibrated simulation results in a more conservative prediction of the source area concentration.

The effects of varying dispersivity are illustrated by Figure 5.7. Both longitudinal and transverse dispersivity were varied for this analysis, as the ratio of the two values was kept constant at 0.1. Increasing the dispersivity by 50 percent resulted in a very minor decrease in the maximum BTEX concentrations (by approximately 600 µg/L)

without a noticeable change in downgradient extent. Decreasing the dispersivity by 50 percent produced a plume with slightly higher BTEX concentrations (by approximately 800 µg/L) without a noticeable change in downgradient extent. This model appears to be insensitive to dispersivity within the range of values evaluated for this analysis.

The effects of varying effective porosity are illustrated by Figure 5.8. Walton (1988) gives a range of 0.15 to 0.35 for the effective porosity of a medium to coarse sand. A comparison of the model using effective porosities that were increased and decreased by 25 percent (to 0.31 and 0.19, respectively) around the calibrated value of 0.25 shows a maximum BTEX concentration difference of approximately 600 µg/L at the source and does not change the plume extent. Therefore, the model is relatively insensitive to the range of reasonable effective porosity values.

The results of the sensitivity analyses suggest that the calibrated model parameters used for this report are appropriate. The calibrated model is very sensitive to the transmissivity and the coefficient of anaerobic decay, and is relatively insensitive to the retardation coefficient, dispersivity, and effective porosity. Increasing the transmissivity and the coefficient of anaerobic decay greatly diminishes the predicted maximum BTEX concentrations, although only the coefficient of anaerobic decay results in an actual destruction of (or decrease in) the mass of BTEX. Lowering the transmissivity or the coefficient of anaerobic decay has a reverse effect, and maximum concentrations of BTEX in the aquifer are greatly increased. The model appears relatively insensitive to the retardation factor and dispersivity; however, variation of values for these parameters contributed toward an appropriate plume configuration.

5.6 MODEL RESULTS

To predict fate and transport of dissolved BTEX compounds at the FT-01 site, three Bioplume II simulations (FT-1-NA, FT-1-BV, and FT-1-Sparge) were run under different sets of conditions. The first simulation (FT-1-NA) assumed the physical weathering processes that currently operate to reduce residual BTEX in source area soils at the site will continue into the future. The second simulation (FT-1-BV) assumed that through the implementation of a soil bioventing system, the soil source is reduced and results in an annual 50-percent decrease in BTEX entering the groundwater per year. The third simulation (FT-1-Sparge) assumed the ROD requirements for additional bioventing in the source area and an air sparging curtain operating until dissolved benzene is reduced to level specified in the ROD (i.e., 5 µg/L). All three models assume that current contamination sources at the site will not increase because the fire training activities at the site ceased more than 5 years ago. Input and output files for each simulation are presented in Appendix D. Model results are described in the following sections.

Each model is evaluated with respect to maximum total BTEX concentrations and the extent of the 5-µg/L total BTEX isopleth. The 5-µg/L isopleth was selected on the basis of the ROD mandated maximum contaminant level (MCL) for benzene (5 µg/L). Because of Bioplume II limitations, the model simulations assume the total BTEX concentration is entirely benzene. Site data indicate that benzene is a relatively minor

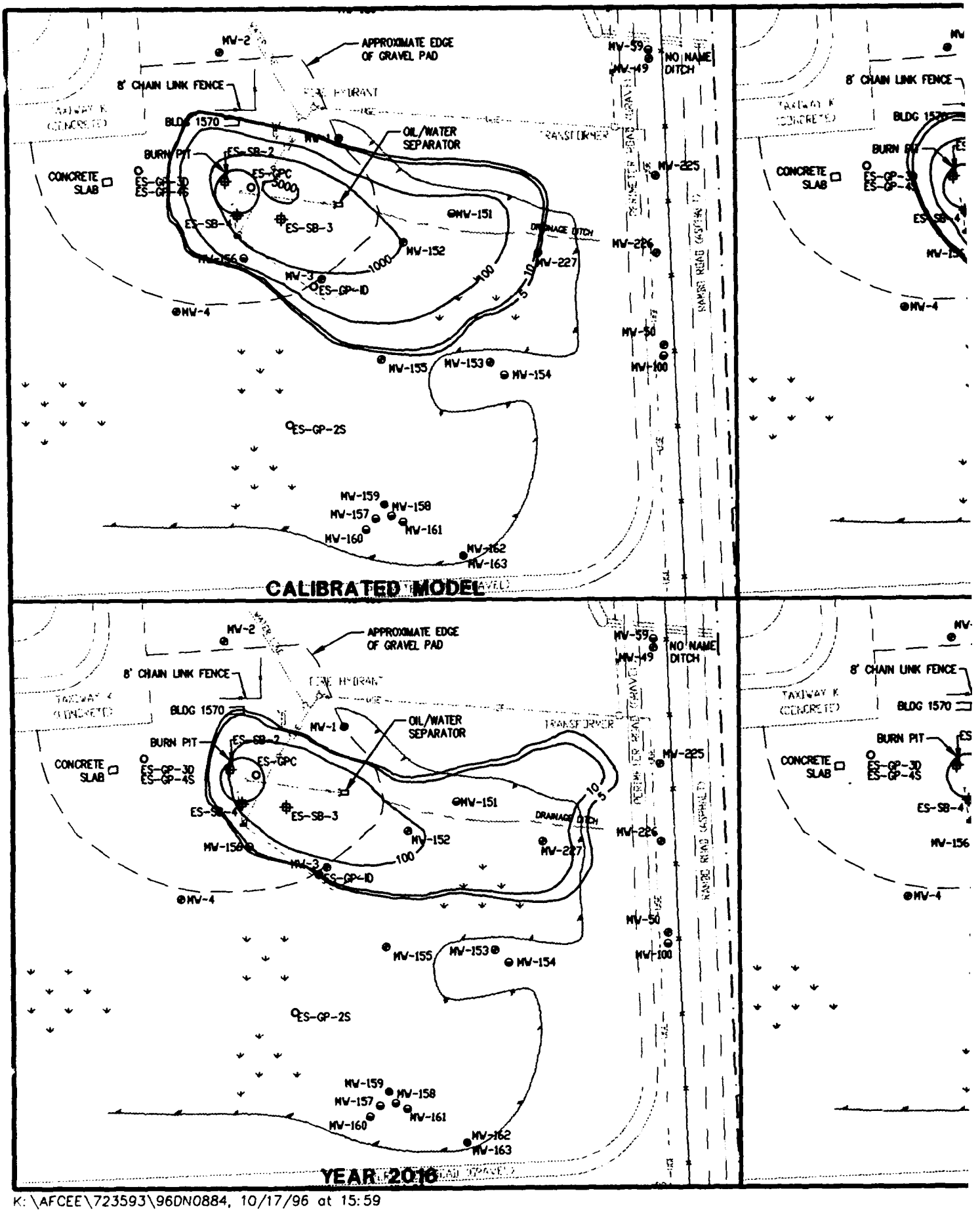
constituent in the dissolved BTEX fraction at Site FT-1 (Table 4.3). Therefore, the selection of the 5-µg/L isopleth likely overestimates the actual future benzene concentrations because current benzene concentrations are less than 17 percent of the total dissolved BTEX mass at the site.

5.6.1 Natural Source Weathering (Model FT-1-NA)

Model FT-1-NA was used to simulate the migration and biodegradation of the BTEX plume assuming that only natural physical weathering decreased BTEX loading in the source area. Physical weathering included dissolution of BTEX from residual contamination in saturated soils into groundwater and from BTEX dissolution into infiltrating precipitation that contacts residual contamination in the vadose zone. This model also assumes that the contaminant source is reduced slightly by volatilization of BTEX in the vadose zone or for chemical or biological degradation of residual product remaining in site soils.

In order to simulate the anticipated decrease in the source size and composition, model FT-1-NA utilizes 28 pumping periods. The first 7 pumping periods are a duplicate of the calibrated model conditions. Each of the following 20 pumping periods has a duration of 1 year and assumes a BTEX injection rate that is approximately 5 percent lower than the previous period as a result of weathering. The source reduction rate of 5 percent per year provided the best match to calibrated conditions in the calibrated model, and is a conservative value for natural source weathering. The final pumping period assumes the source has been removed through weathering, and simulates the long-term fate of the groundwater plume for an additional 20 years.

This model predicts decreasing maximum plume concentrations, with the plume reaching a maximum downgradient extent in approximately 10 years. Figure 5.9 shows the modeled plume for 2006 (10 years of simulated weathering), 2016 (20 years of simulated weathering), and 2030 (34 years of simulated weathering). After 10 years, the modeled downgradient extent of the 5-µg/L BTEX isopleth has migrated a maximum of 100 feet further downgradient; however, the 100-µg/L contour has remained unchanged. At the modeled maximum downgradient extent, the BTEX plume does not leave the site or impact any potential receptor exposure points. Within the source area, the extent of the 1,000-mg/L contour has retreated approximately 200 feet toward the source area, and the maximum BTEX concentration decreases by 74 percent, from approximately 5,660 µg/L to 1,350 µg/L. (Figure 5.9). After 20 years of weathering (year 2016), the 5-µg/L isopleth has receded to approximately 100 feet downgradient from the calibrated position and total BTEX concentrations have decreased to a maximum of 798 µg/L or 14 percent of the calibrated maximum concentration. After 34 years of natural weathering, the model suggests that the groundwater plume will have almost completely attenuated, with a maximum BTEX concentration of 7 µg/L (Figure 5.9). Further model simulation suggests that after 34 years, the plume is completely degraded to below 5 µg/L.



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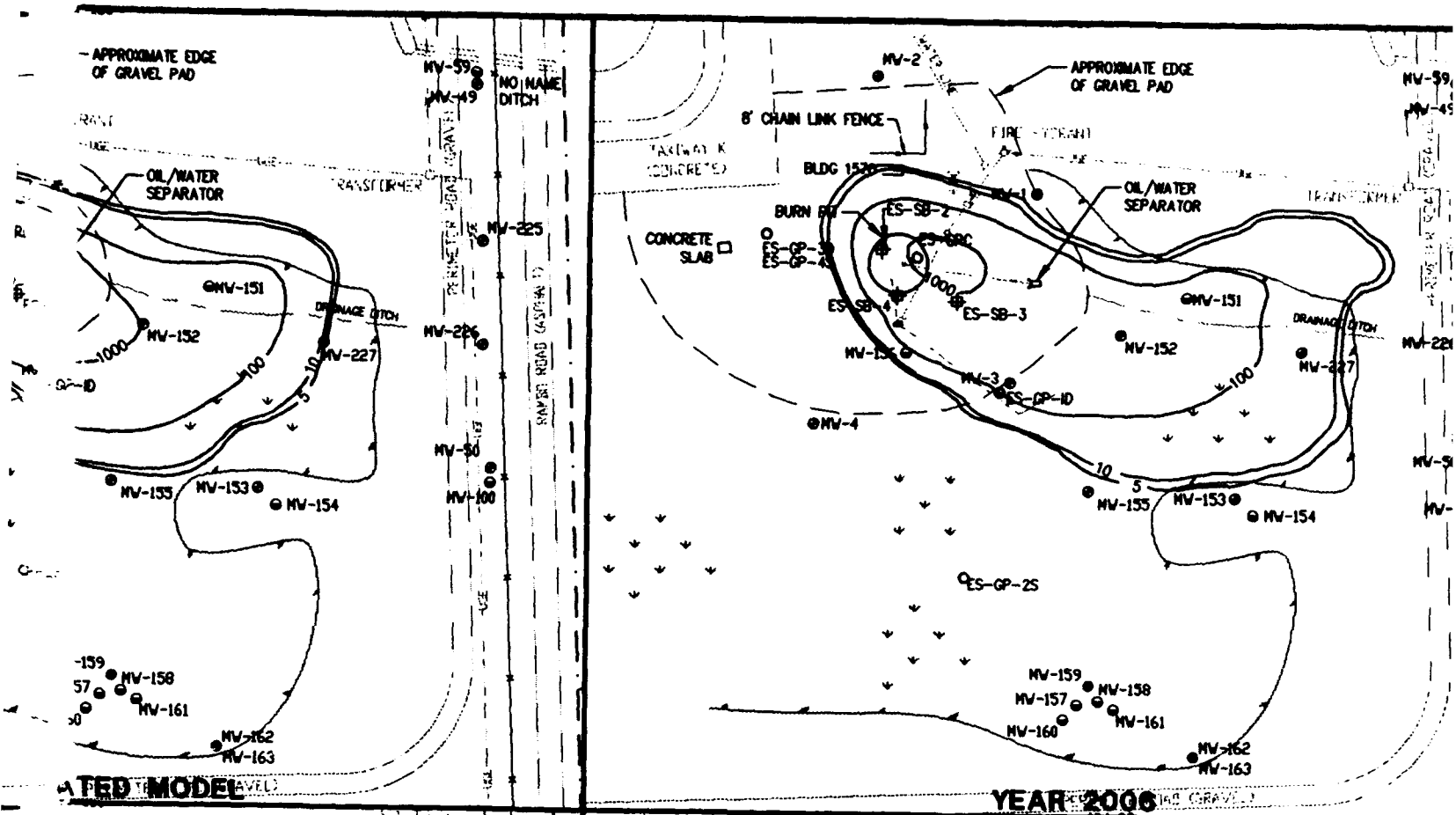
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OIL/WATER SEPARATOR
TRANSFORMER
PERIMETER ROAD (GRAVEL)
RAMP RD (ASPHALT)
DRAINAGE DITCH
MV-59
MV-49
MV-225
MV-151
MV-152
MV-227
MV-226
MV-50
MV-100
MV-155
MV-153
MV-154
MV-159
MV-158
MV-161
MV-162
MV-163
1000
100
10
5
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
TAXIWAY K (CONCRETE)
BLDG 1520
MV-2
MV-1
OIL/WATER SEPARATOR
BURN PIT
ES-SB-2
ES-GPC
CONCRETE SLAB
ES-GP-3D
ES-GP-4S
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MV-4
ES-GP-2S
MV-157
MV-160
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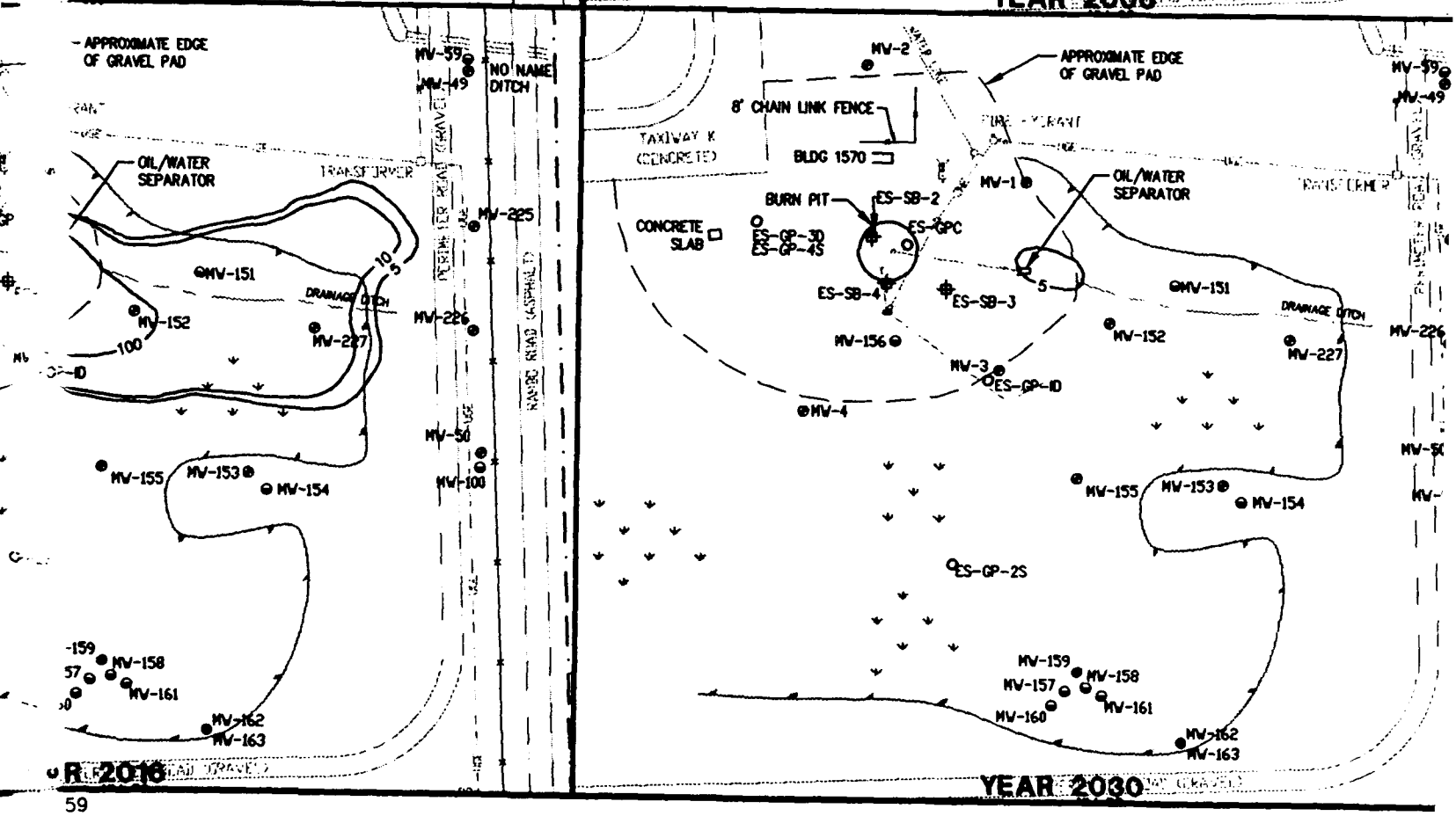
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TAXIWAY K (CONCRETE)
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ES-GPC
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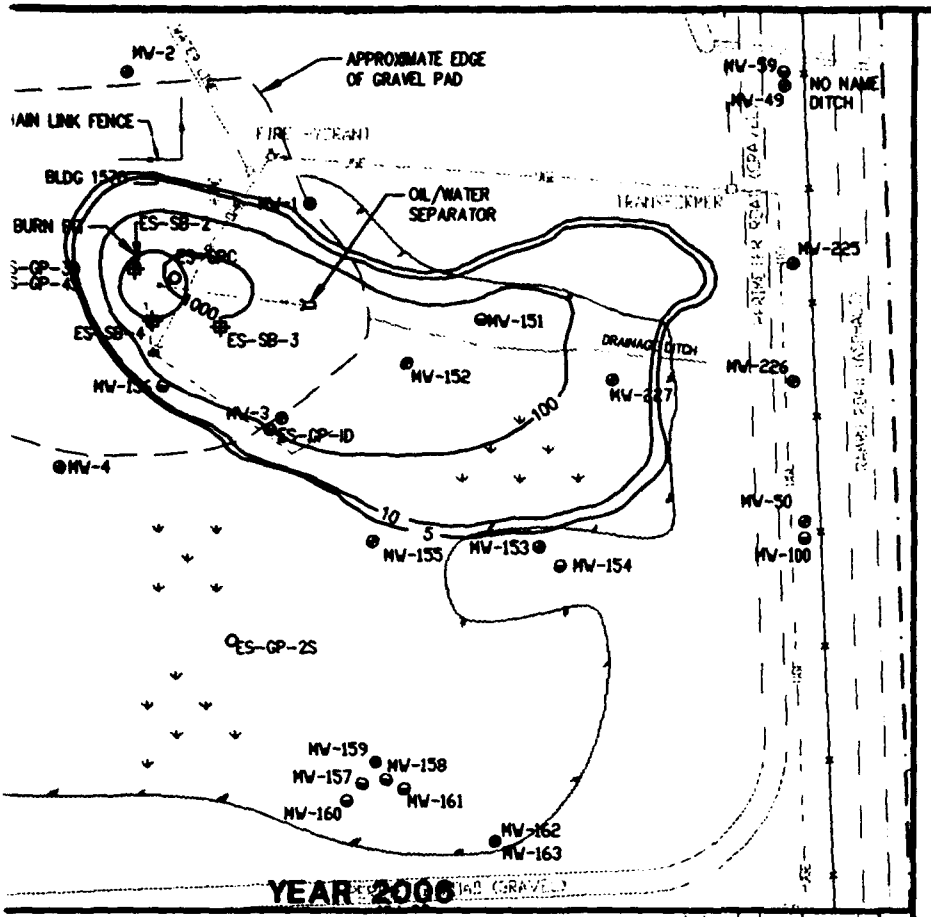
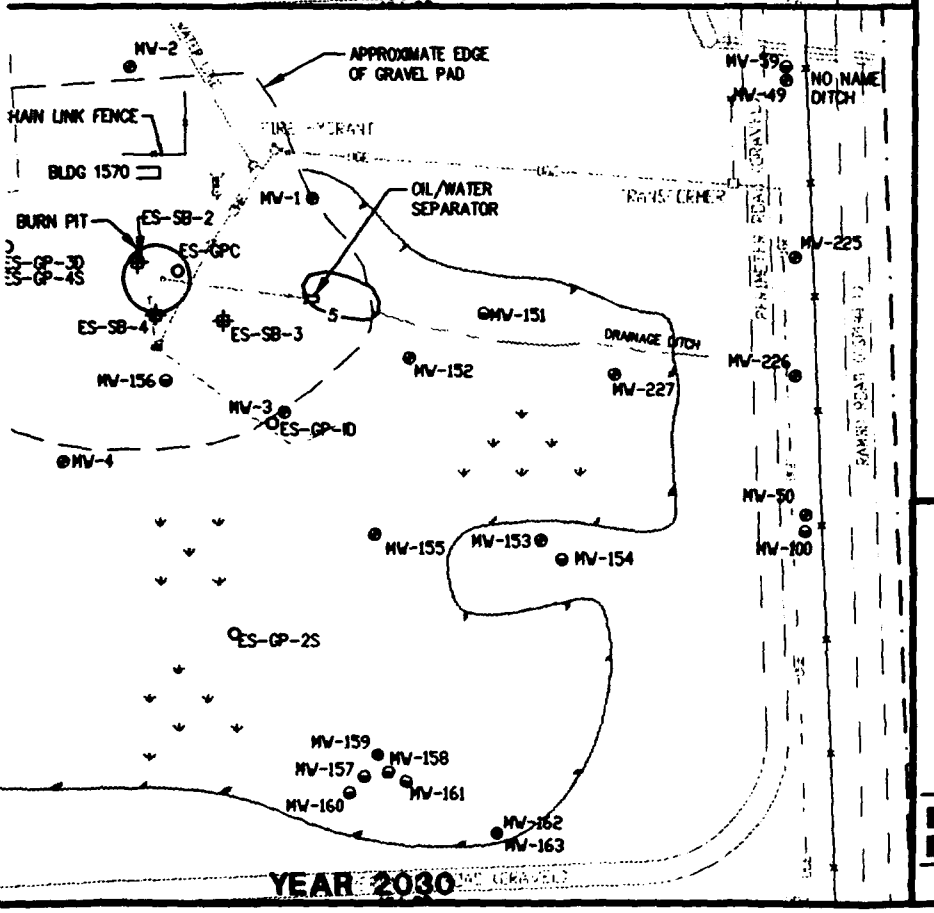
YEAR 2030





LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- TEMPORARY MONITORING POINT
- SOIL SAMPLE LOCATION
- —10— LINES OF EQUAL BTEX CONCENTRATION (µg/L)

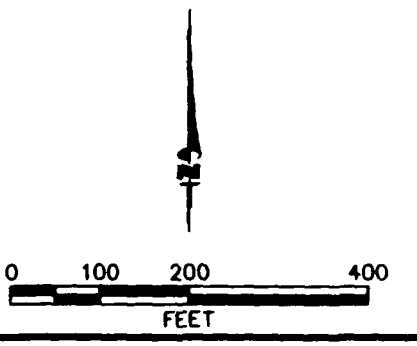


FIGURE 5.9

MODEL FT-1-NA PREDICTED PLUME MIGRATION

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

These results suggest that the maximum observed BTEX concentrations will steadily decrease over the next 34 years without any further engineered removal (i.e., assuming only physical weathering is taking place in source soils). Furthermore, the results suggest that the downgradient extent of the plume may increase by approximately 100 feet over the next 10 years, but that the maximum plume concentrations will be steadily decreasing. Therefore, physical source weathering should be sufficient to reduce the dissolved BTEX concentrations and limit any future downgradient migration of the plume to the no name ditch.

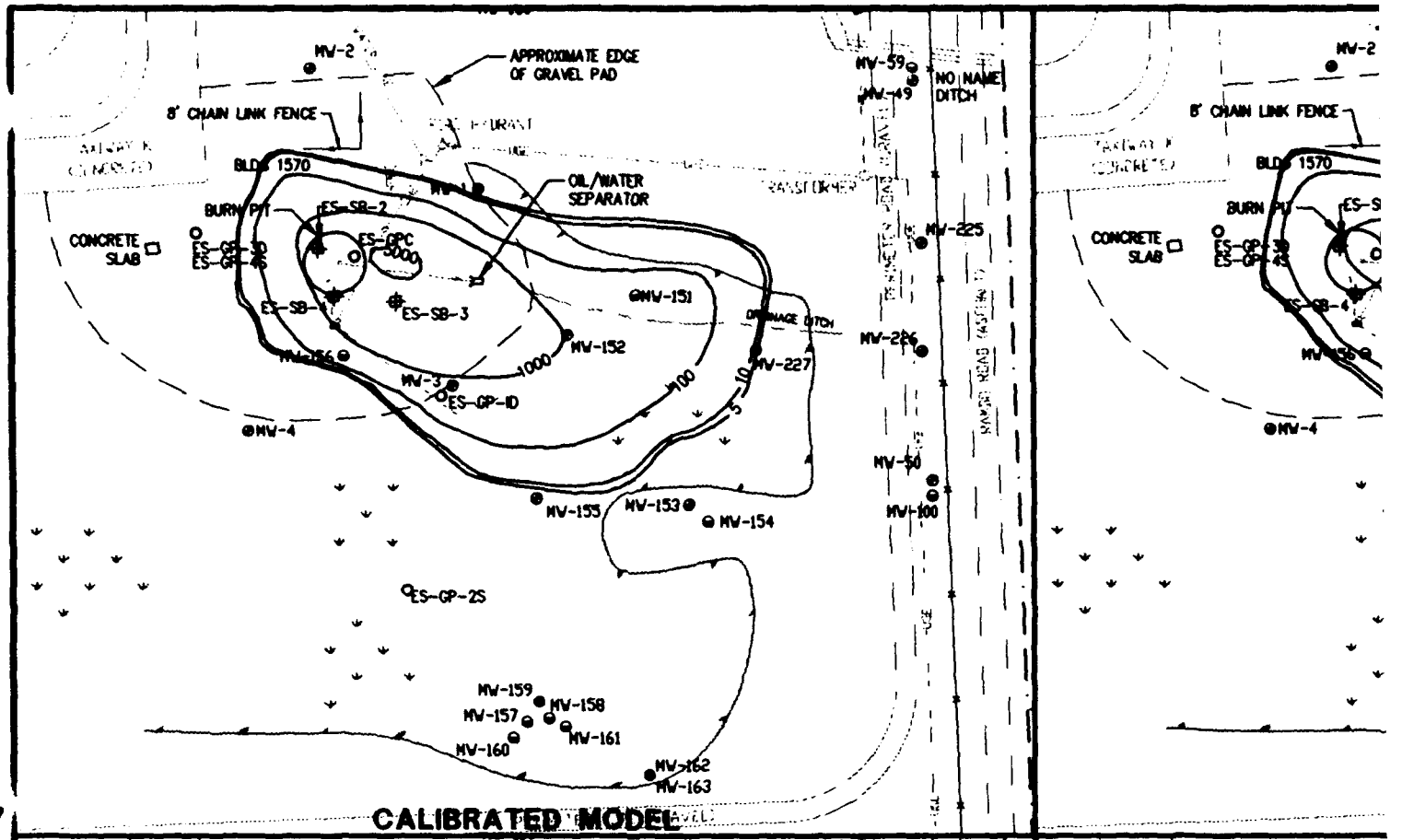
5.6.2 Engineered Source Reduction (Model FT-1-BV)

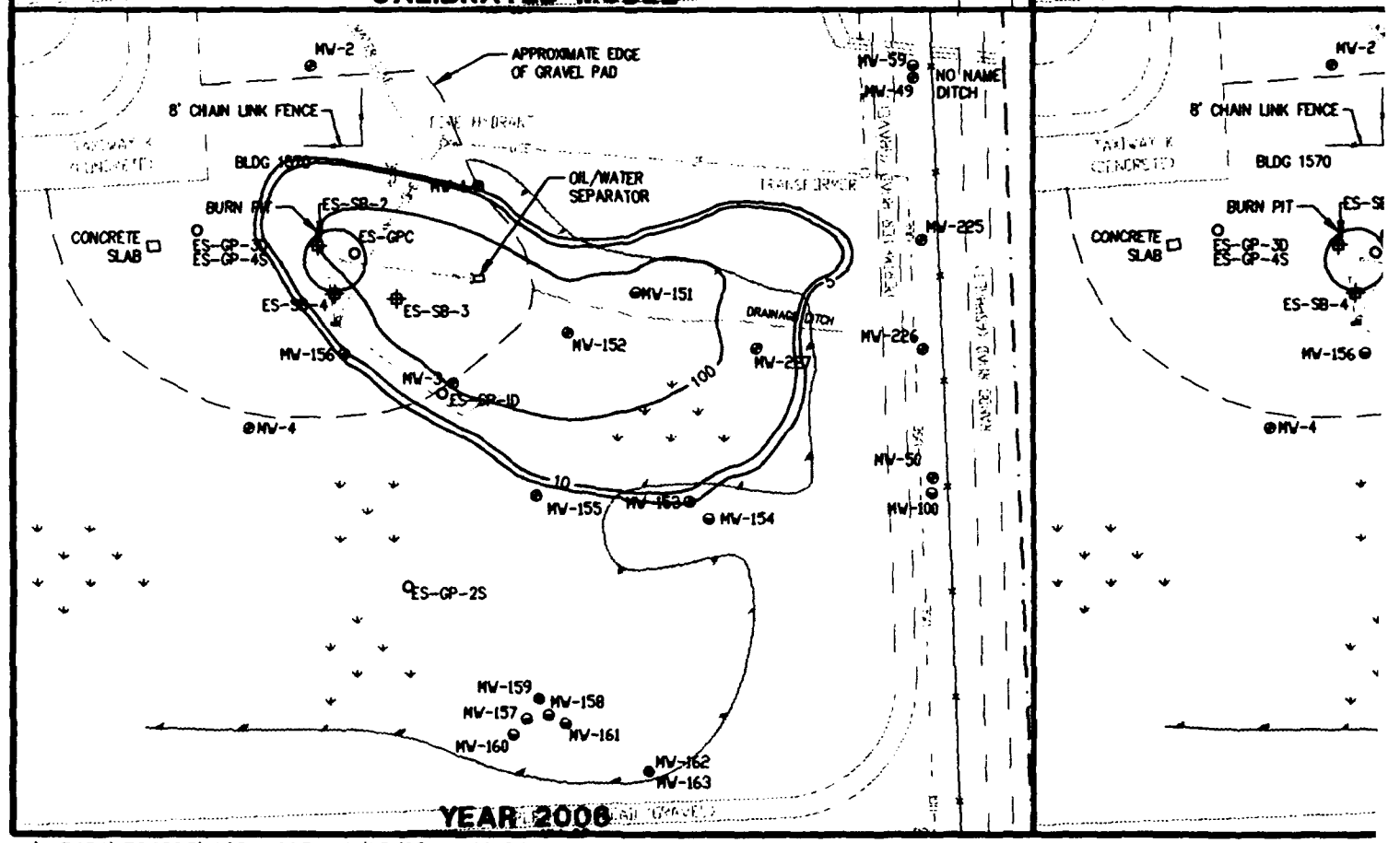
To illustrate the impact of engineered source reduction activities upon dissolved BTEX migration, model FT-1-BV incorporates decreasing BTEX loading rates, under the assumption that an expanded bioventing system will be used to remediate the source areas. Bioventing is an *in situ* bioremediation process where low-flow air injection is used to enhance the biodegradation of organic contaminants in the subsurface vadose zone soil by supplying oxygen to indigenous microbes. Bioventing was simulated in model FT-1-BV through an annual 50-percent reduction in BTEX loading rates over a 3-year period.

The FT-1-BV model assumptions are conservative when compared to anticipated BTEX mass removal from soil bioventing. Implementation of bioventing soil remediation has been accompanied by reductions in soil BTEX concentrations averaging over 90 percent per year at a group of 16 other sites (AFCEE, 1994). Furthermore, soil sampling results collected during the FT-1 bioventing pilot study (Parsons ES, 1996) indicate that source reduction was greater than 50 percent. Therefore, assuming a 50-percent reduction in BTEX mass may underestimate the actual impact of a bioventing system on BTEX loading to site groundwater, and effectively lengthen the predicted remediation time.

Model FT-1-BV was run with 11 pumping periods. The first 7 periods are a duplicate of the calibrated model. The next 3 pumping periods each last one year and include BTEX loading rates that decrease geometrically at 50 percent per year. After these 3 periods less than 0.1 percent of the original source remains. The final pumping period is continued for an additional 20 years to simulate the long-term fate and transport of the plume. While it is difficult to quantify the actual decrease in the BTEX loading rates that will be brought about by bioventing, a model based on these assumptions can provide a useful indication of the potential effects of source reduction.

This model predicts a rapid decrease in source area BTEX concentrations followed by a slower decrease in the areal extent of the plume. Figure 5.10 presents model results for the years 1999 (3 years after implementation of bioventing), 2006 (10 years after implementation of bioventing), and 2019 (33 years after implementation of bioventing). Three years after implementation of bioventing, the dissolved plume (as defined by the 5-µg/L isocontour) has not migrated beyond the calibrated plume extent. The maximum source-area BTEX concentration has decreased 57 percent, from approximately 5,660 µg/L to 2,440 µg/L. The model predicts that the downgradient





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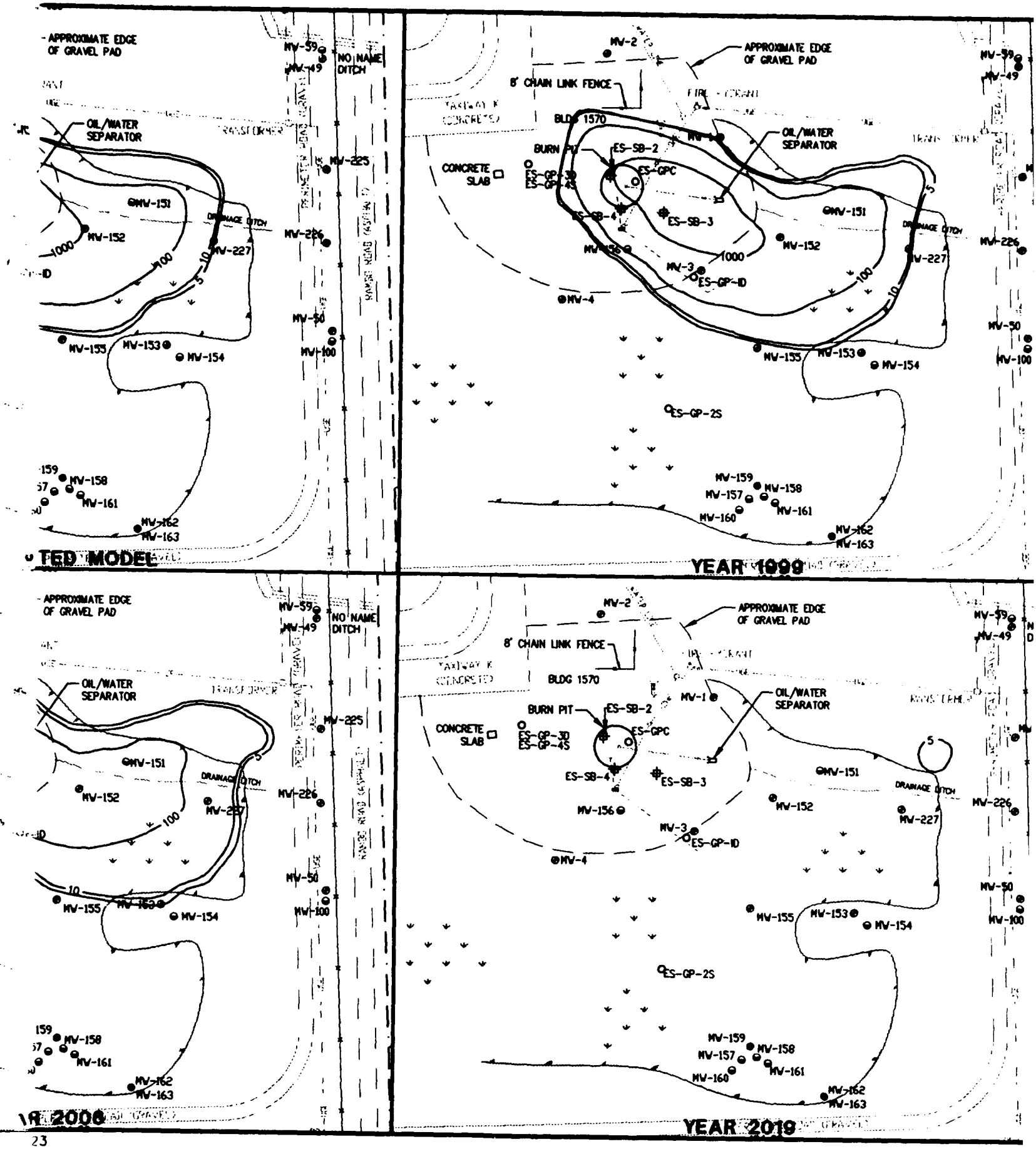
APPROXIMATE EDGE OF GRAVEL PAD
NO NAME DITCH
OIL/WATER SEPARATOR
DRAINAGE DITCH
MV-59
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TED MODEL
MV-2
8' CHAIN LINK FENCE
BLDG 1570
BURN PIT
ES-SB-2
ES-GPC
CONCRETE SLAB
ES-GP-3D
ES-GP-4S
ES-SB-4
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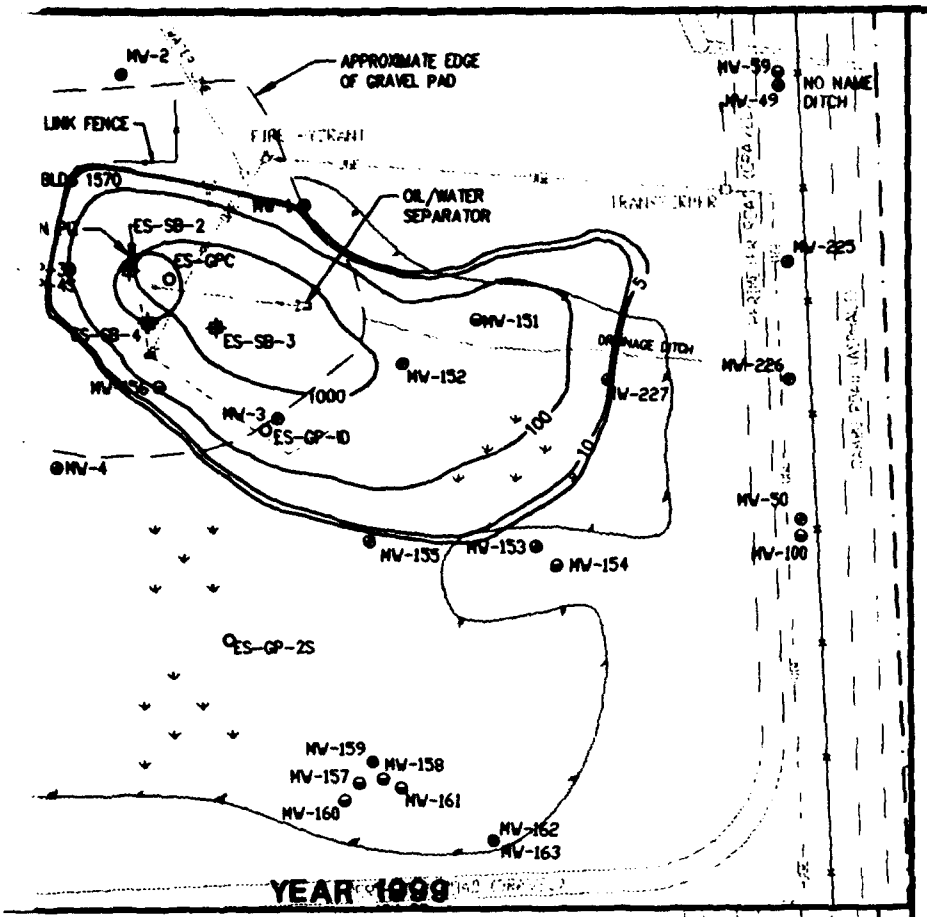
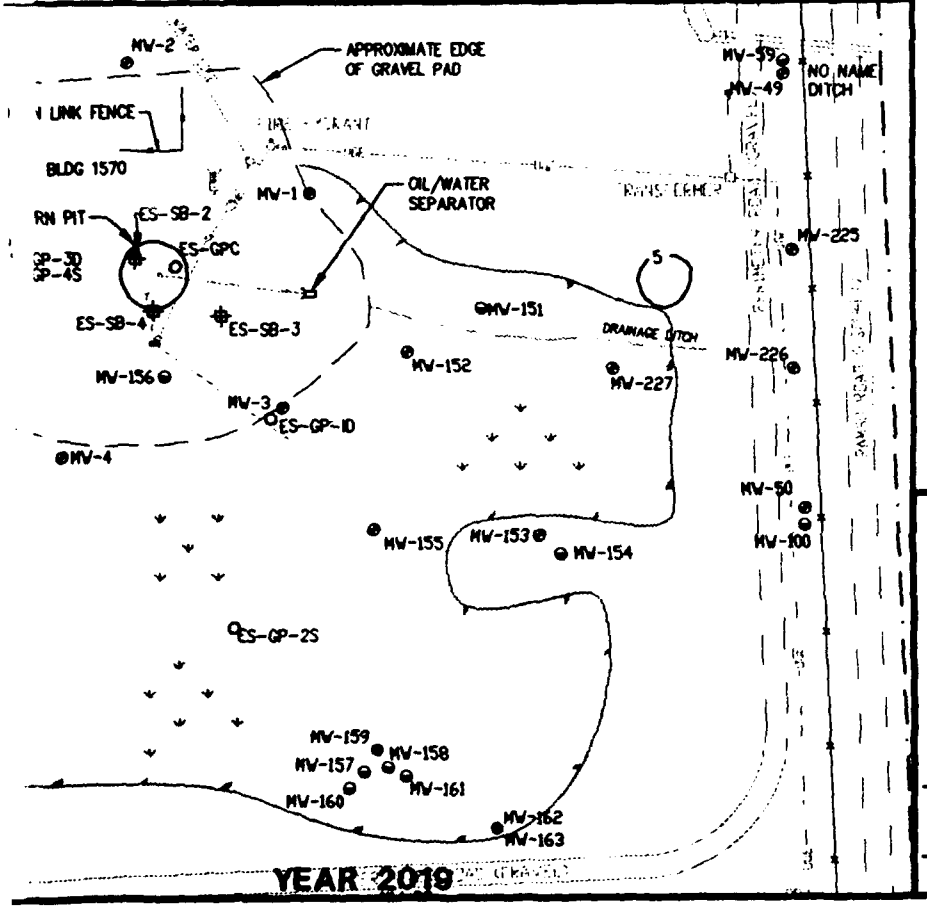
YEAR 1999
YEAR 2019





LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- TEMPORARY MONITORING POINT
- SOIL SAMPLE LOCATION
- —10— LINES OF EQUAL BTEX CONCENTRATION (µg/L)

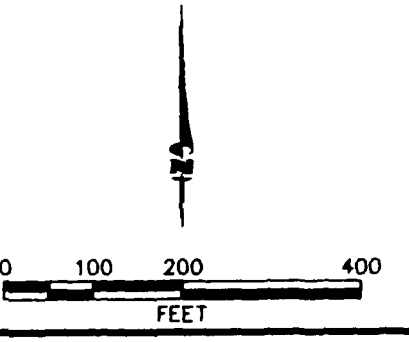


FIGURE 5.10

MODEL FT-1-BV PREDICTED PLUME MIGRATION

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

plume extent will remain at the calibrated plume extent. The maximum predicted BTEX concentration in year 2006 is less than 94 percent of that in the calibrated model. After 23 years of active and passive remediation, the plume has detached from the source area, and the maximum simulated BTEX concentration (5.6 µg/L) lies downgradient from the source area. The model predicts that the maximum BTEX concentration will be less than 5 µg/L 23 years after the re-initiation of bioventing.

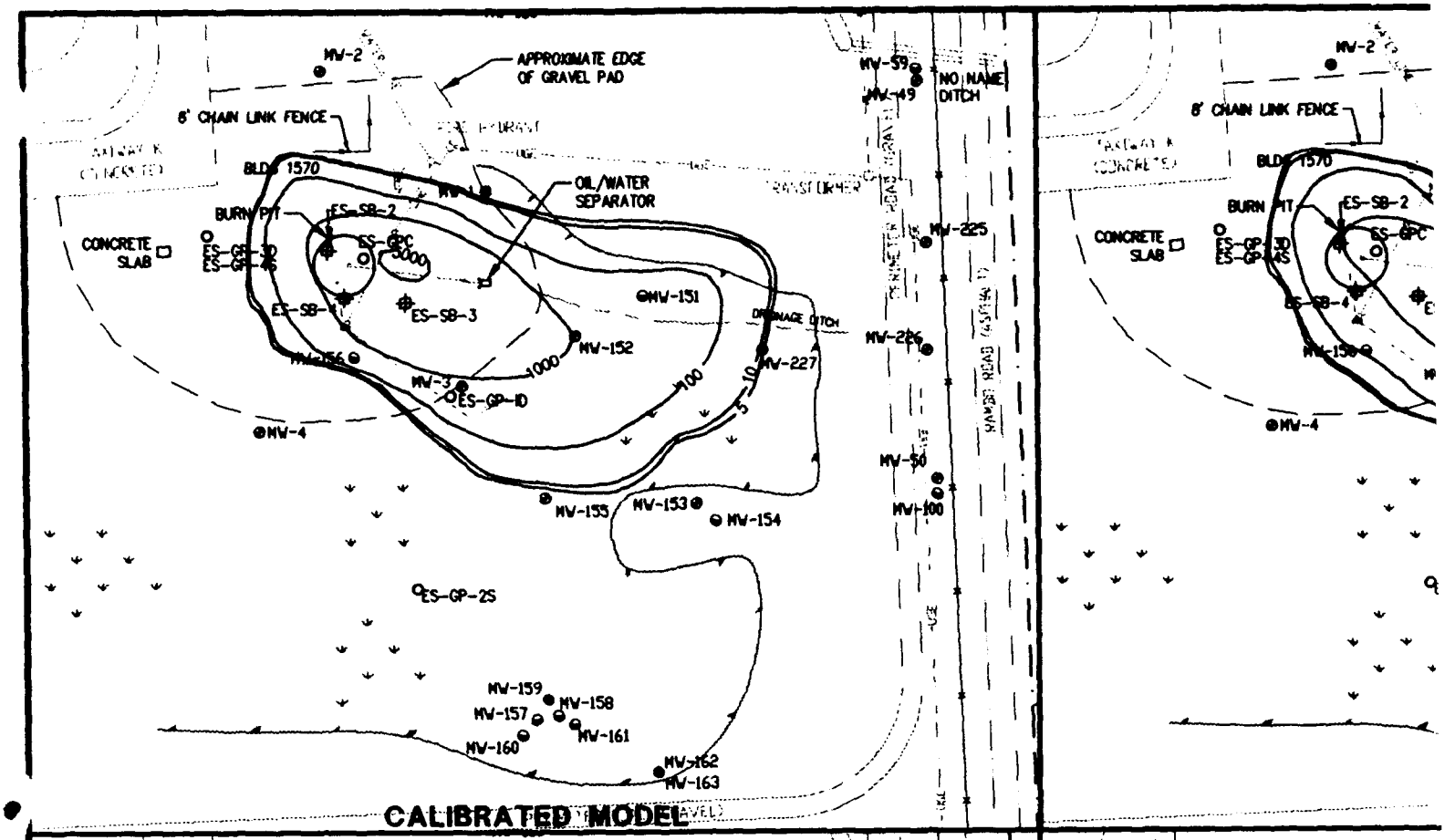
5.6.3 Air Sparging and Bioventing (Model FT-1-Sparge)

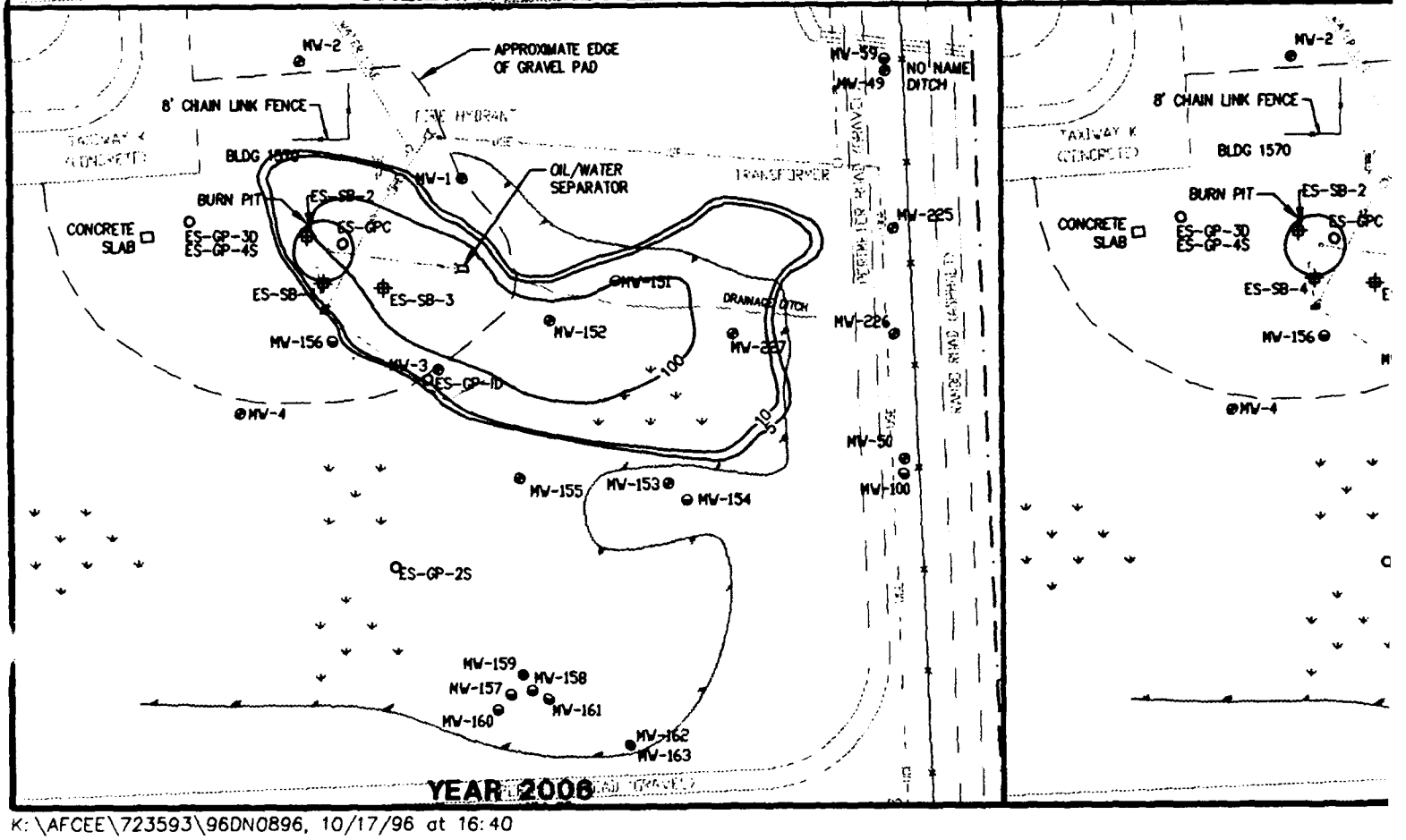
Model FT-1-Sparge was run to illustrate the scenario of bioventing and air sparging specified in the ROD for the FT-1 site. Air sparging is the least conservative of the three scenarios modeled for this site. The bioventing scenario from the previous model was used for the BTEX loading at the 7 cells representing the source area. In order to simulate an air sparging curtain, injection wells were added to 9 model cells immediately downgradient from the gravel pad (Figure 5.1). The injection wells were assumed to increase the DO concentration in the cells to approximately 6.0 mg/L. As in the two previous models, the first seven pumping periods are a copy of the calibrated model. The next three 1-year pumping periods simulate the start of the air sparging system, and the BTEX source loading is reduced in the source area through bioventing. The remaining pumping period continues to simulate the long-term fate and transport of the plume with only the air sparging wells operating until BTEX contamination has been reduced below 5 µg/L.

This model predicts a slightly faster decrease in maximum groundwater BTEX concentrations in the source area over a 10-year period. Figure 5.11 presents model predictions for 3, 10, and 19 years of remediation. Simulated maximum BTEX concentrations for this model decrease approximately 62 percent in the first 3 years, from 5,660 µg/L to 2,165 µg/L. The 10-year simulation (year 2006) predicts source-area BTEX concentrations will decrease by over 96 percent to a maximum predicted BTEX concentration of 240 µg/L. At this time, the model predicts the plume to be slightly narrower in the area of the air sparging wells, expanding to the calibrated width at the downgradient extent. In addition, the downgradient plume extent has advanced approximately 50 feet. At year 19 (2015) the model suggests that the plume will be detached from the source area, with a maximum BTEX concentration of 8.4 µg/L. After year 19, total BTEX levels are below 5 µg/L.

5.7 CONCLUSIONS AND DISCUSSION

Three model scenarios were used to predict BTEX attenuation and migration rates at the FT-01 site. The first scenario, model FT-1-NA, assumed natural physical weathering of the residual soil source contamination. The second scenario, model FT-1-BV, assumed that as a result of the operation of a bioventing system, the source of dissolved BTEX would be completely eliminated in 3 years. Model FT-1-Sparge assumes removal of the BTEX source in soils through bioventing and installation of an air sparging system to treat dissolved BTEX downgradient from the source area. The results of all three Bioplume II model scenarios suggest that dissolved BTEX will not





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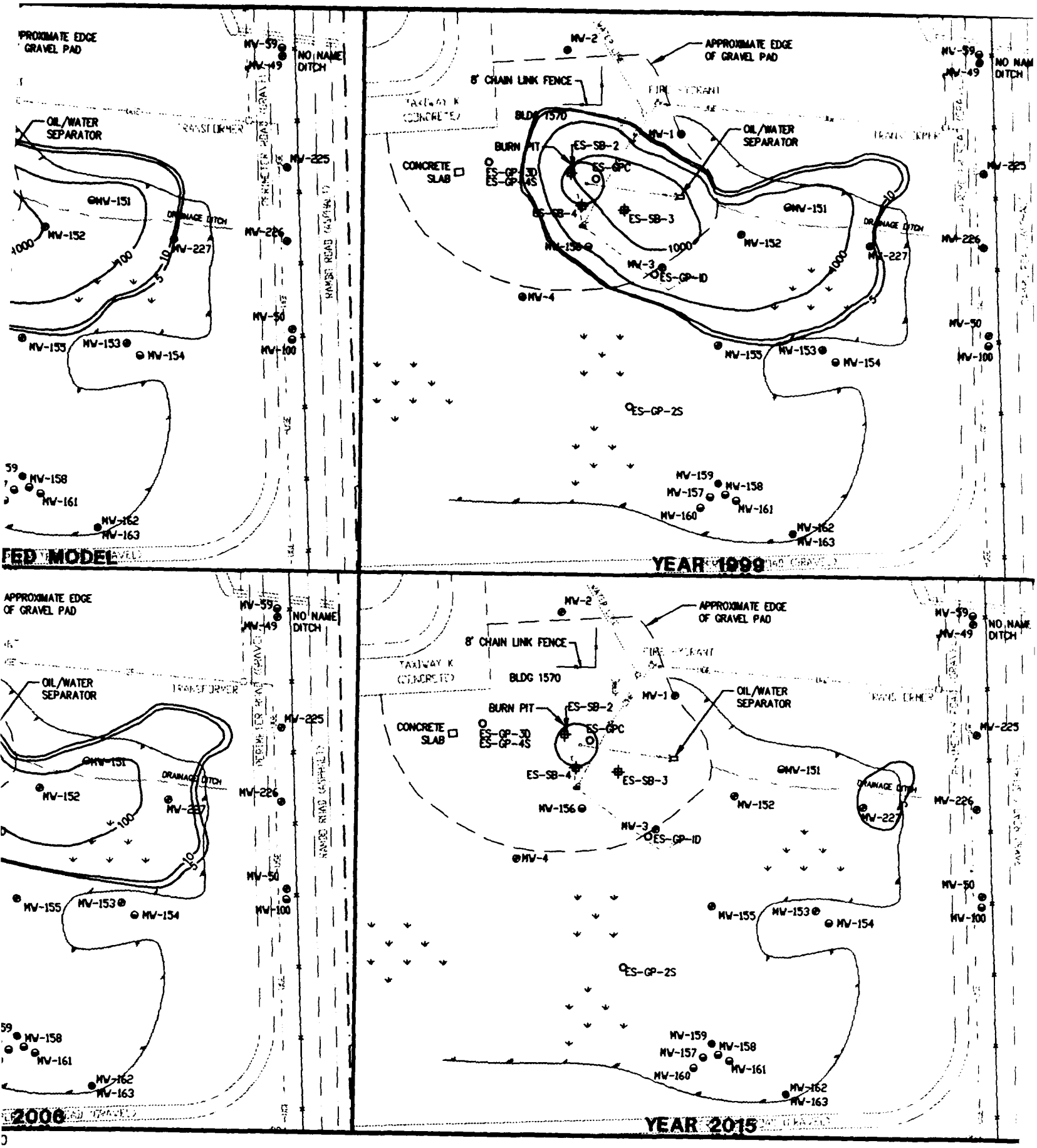
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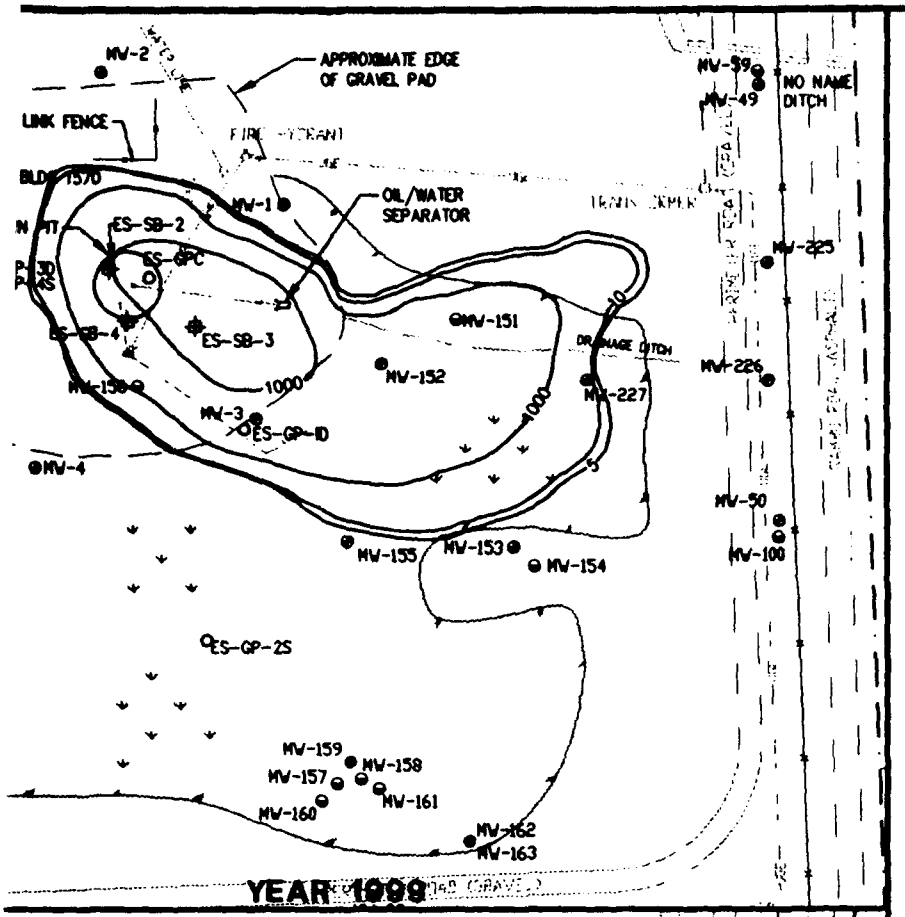
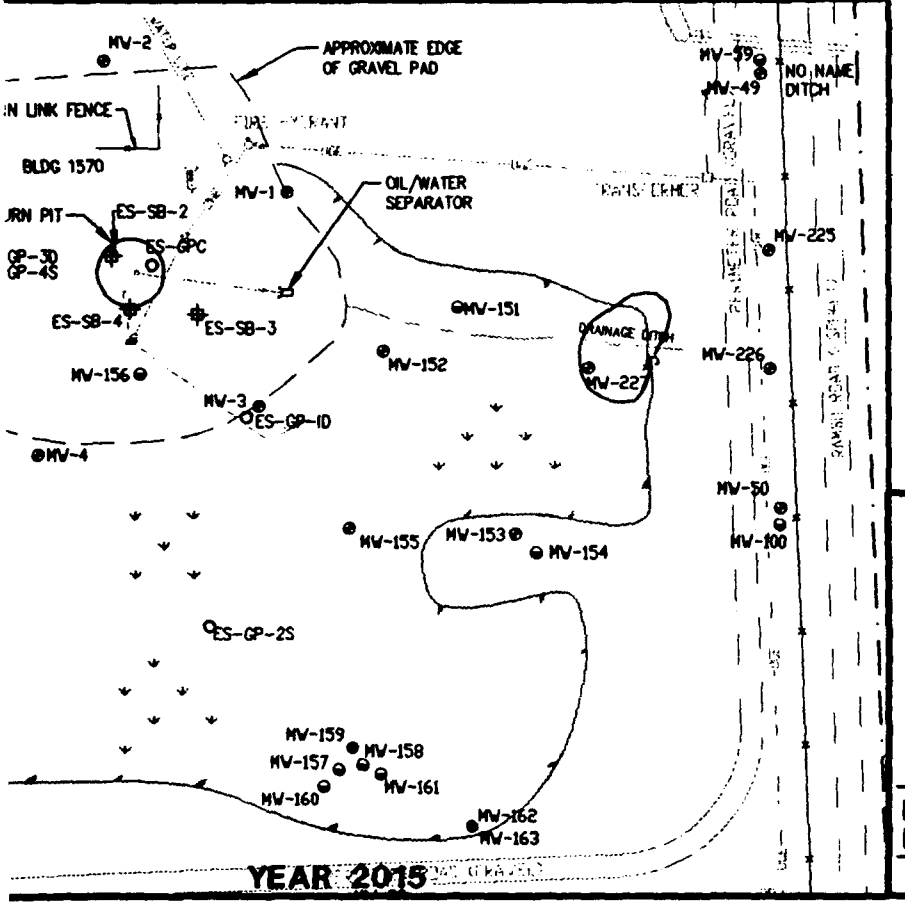
MW-153
MW-154
MW-158
MW-161
MW-162
MW-163
FED MODEL
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
BLDG 1570
BURN PIT
ES-SB-2
ES-GPC
CONCRETE SLAB
ES-GP-3D
ES-GP-4S
MW-1
ES-SB-4
ES-SB-3
MW-156
MW-3
ES-GP-1D
MW-4
ES-GP-2S
MW-159
MW-157
MW-160
YEAR 1999
2006
YEAR 2015





LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- TEMPORARY MONITORING POINT
- SOIL SAMPLE LOCATION
- —10— LINES OF EQUAL BTEX CONCENTRATION (µg/L)

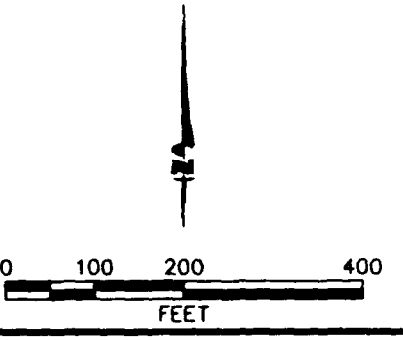


FIGURE 5.11

MODEL FT-1-SPARGE PREDICTED PLUME MIGRATION

Site FT-1
Remediation By Natural Attenuation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

migrate more than 100 feet beyond the current plume front (i.e., will not reach the ditch along perimeter road).

Model FT-1-NA results suggest that the BTEX plume will be completely degraded by natural weathering processes after approximately 34 years. Using bioventing and a combination of bioventing and air sparging, models FT-1-BV and FT-1-Sparge predict that complete remediation of the dissolved BTEX plume will require approximately 23 and 19 years, respectively. All three models predict that the leading edge of the plume will advance no more than 100 feet as remediation by natural attenuation of dissolved groundwater BTEX concentrations proceeds.

In all model simulations, several conservative assumptions are built into the model. The use of these conservative model assumptions suggests that natural attenuation of BTEX contamination at the site may exceed model predictions. These conservative model assumptions include:

1) Aerobic respiration, iron reduction, sulfate reduction, and methanogenesis all are occurring at this site; however, only the anaerobic processes are effectively simulated in the models. Aerobic processes are effectively simulated within the core of the plume where they potentially account for less than 6 percent of degradation. At the leading edge of the plume, however, the aerobic contribution is more significant and is very likely underestimated by a first order biodegradation rate. In addition, aerobic biodegradation may potentially become more important within the core of the plume as residual BTEX source concentrations are removed, thereby allowing more oxygenated rainwater to percolate through vadose zone soils.

2) The stoichiometry used to determine the ratio between electron acceptors and total BTEX assumed that no microbial cell mass was produced during the reactions. As discussed in Section 4.3.2, this approach may be too conservative by a factor of three.

3) Dissolved oxygen was only introduced with groundwater recharge at the upgradient model boundary; however, groundwater recharge occurs across the entire site as a result of precipitation.

4) A low coefficient of retardation for benzene (2.50) was used for all the BTEX compounds in the model simulations. Minimum retardation coefficient values for the other BTEX compounds range from 6.27 to 14.0. The use of a conservative retardation coefficient tends to increase the velocity of contaminant migration, but may provide a more accurate estimate of benzene transport. However, realistic retardation coefficients for toluene, ethylbenzene, and xylenes are higher than that for benzene, which will slow the actual migration of these compounds, thereby increasing their susceptibility to biodegradation.

5) The decay constant of 0.001 day^{-1} is conservative when compared to literature values of 0.001 day^{-1} to 0.19 day^{-1} (see Section 5.3.5.3). The use

of a low decay constant increases the travel distance of the contaminant plume, as well as the time required for natural attenuation.

6) Calibrated source concentrations in the models were higher than observed concentrations. This introduction of extra contaminant mass likely results in the predictions being conservative because additional BTEX mass must be biodegraded to produce the observed results.

The three model simulations were run in order to account for uncertainties associated with the assumptions of future site conditions. The patterns of degradation of the plumes shown in models FT-1-NA, FT-1-BV, and FT-1-Sparge are feasible, given the observed BTEX concentrations, the conservative assumptions made in constructing the simulations, and the strong evidence of biodegradation. Model FT-1-NA is a "worst-case" scenario in that it assumes BTEX dissolution into the aquifer will continue while the source is being naturally weathered. Without engineered source reduction, BTEX contamination in that model remains for 34 years. Models FT-1-BV and FT-1-Sparge are more optimistic predictions which assume active source reduction will rapidly reduce the BTEX in site soils and therefore reduce any further dissolution into the groundwater. This results in more rapid attenuation of the dissolved BTEX plume.

SECTION 6

REMEDIATION ALTERNATIVE AND GROUNDWATER COMPLIANCE MONITORING

The ROD for Site FT-1 (HNUS, 1993a) specifies maintaining institutional controls, implementing bioventing and air sparging to remediate soils and restore groundwater to drinking water quality, and monitoring off-site groundwater supply wells in the vicinity of the site. Institutional controls currently established under the authority of the Base commander restrict access to and use of groundwater throughout the Base (HNUS, 1993a). An *in situ* soil bioventing system will be installed within the FT-1 source area and operated until the soil cleanup level of 0.5 mg/kg for benzene is achieved. The air sparging system will be placed within the dissolved BTEX plume near the eastern edge of the gravel pad plume and operated until dissolved benzene concentrations are less than 5 µg/L throughout the plume [i.e., the points of compliance (POCs) for the groundwater plume include all points throughout the plume (HNUS, 1993a)]. A groundwater monitoring strategy demonstrate compliance will be developed during the remedial design phase. The final ROD requirement specifies that offsite groundwater supply wells must be monitored to prevent the consumption by area residents of groundwater containing site-related contaminants at concentrations exceeding drinking water quality standards (HNUS, 1993a).

The intent of this TS is to evaluate how natural attenuation of the groundwater COC, benzene, complements the ROD-specified remediation systems to achieve the numerical cleanup goal for groundwater mandated in the ROD for FT-1. In addition to benzene, this TS evaluates RNA of the other BTEX compounds and the CAHs detected in site groundwater. The ability of natural attenuation processes to remediate these contaminants dissolved in groundwater at FT-1 is demonstrated in Section 4. In Section 5, predictions made using conservative models suggest that these processes, acting either alone or in conjunction with ROD-specified technologies, can reduce organic contaminant concentrations and limit plume migration. Therefore, natural attenuation will factor into site groundwater remediation. The remainder of this section is devoted to outlining the site remedial objectives and evaluating the effectiveness of the ROD-specified remediation alternative through long-term groundwater compliance monitoring.

6.1 GROUNDWATER REMEDIAL OBJECTIVES

The short-term remediation objective for shallow groundwater within and downgradient from FT-1 is limiting plume expansion to prevent exposure of downgradient receptors to concentrations of benzene in groundwater at levels that

exceed 5 µg/L, as specified in the ROD. Results of the conservative numerical models suggest that BTEX concentrations in excess of 5 µg/L are not likely to migrate more than 600 feet downgradient from the source area (Figures 5.9 through 5.11). Because, the models assume the BTEX concentration consists entirely of benzene, the downgradient plume extent for benzene may be overestimated.

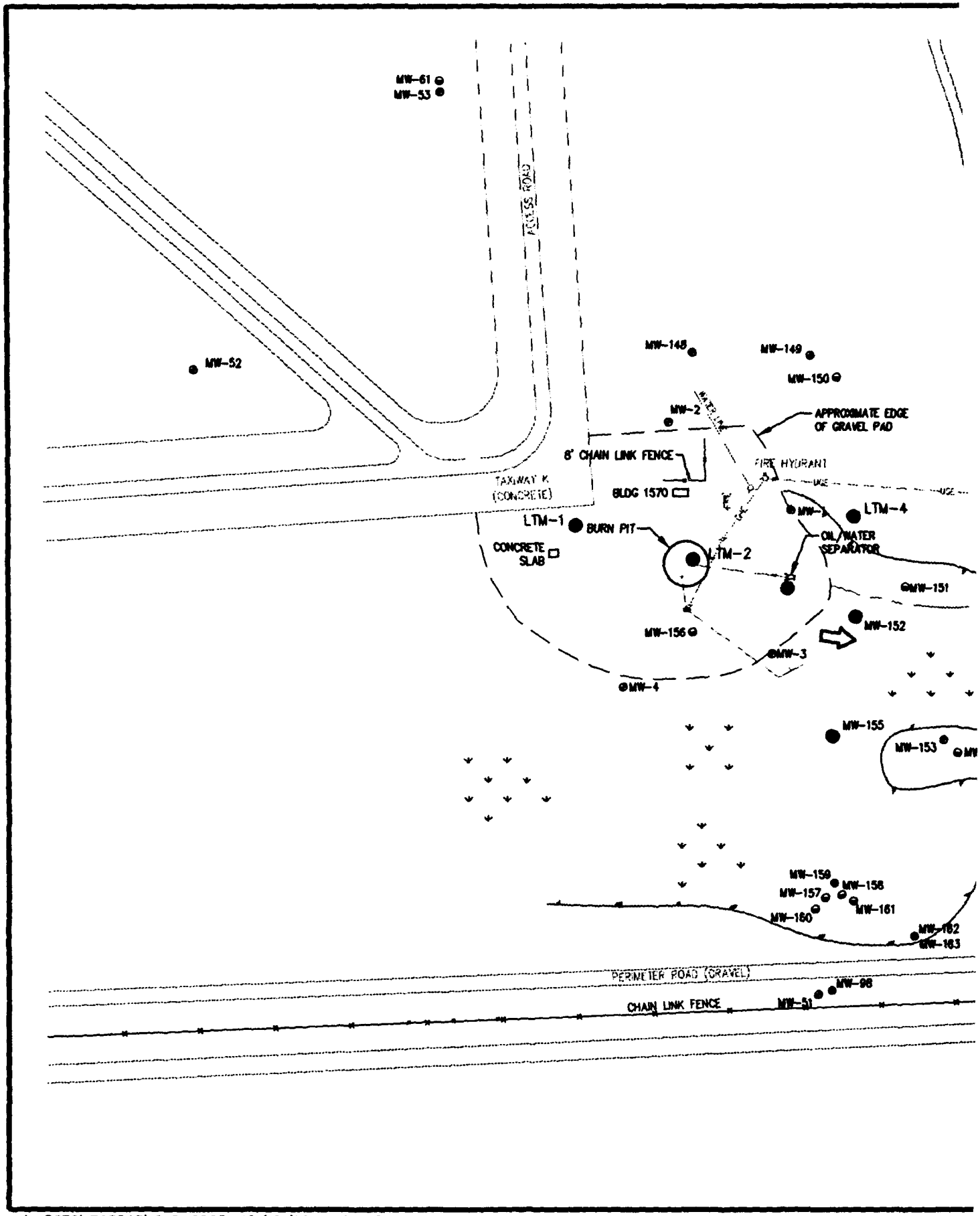
Available data suggest that receptor exposure pathways involving shallow groundwater are not complete under current conditions; however, a pathway could be completed in the future if shallow groundwater within approximately 750 feet downgradient from the burn pit is used as a potable water supply. However, because of institutional controls invoked by the ROD on groundwater use within the remediation zone, the completion of potential future exposure pathways is not likely. The institutional controls must remain in effect until it can be demonstrated that the potential for receptor exposure to dissolved benzene at concentrations greater than 5 µg/L no longer exists.

The long-term remedial objective for shallow groundwater at the POC (i.e., throughout the plume) is attainment of the ROD cleanup goal for dissolved benzene (5 µg/L) throughout the plume. Although it is unlikely that groundwater from the plume would be ingested by humans, this level of long-term protection has been deemed appropriate. To attain the benzene cleanup goal, an air sparging curtain will be installed in the anaerobic zone of the BTEX plume.

6.2 LONG-TERM GROUNDWATER COMPLIANCE MONITORING

The strategy described in this section is designed to monitor benzene plume migration over time and to demonstrate the effectiveness of selected remedial alternative at complying with site groundwater remediation objective specified in the ROD. Although not specified in the rod, it is recommended that chlorinated solvent compounds be included in the long-term groundwater compliance monitoring program because dissolved concentrations of TCE, DCE, and vinyl chloride currently exceed regulatory criteria. Ten LTM locations have been selected for the proposed compliance monitoring program (Figure 6.1). Existing monitoring wells can be incorporated into the proposed long-term compliance monitoring program at six of the locations; new wells will be required at the remaining four locations.

Five of the proposed long-term compliance monitoring wells are along the axis of the plume. Proposed well LTM-1, located approximately 200 feet east-northeast from the burn pit, will be used to monitor the quality of groundwater upgradient from the source area and remediation zone. Proposed well LTM-2 will be installed within the burn pit in order to monitor source area benzene concentrations and groundwater geochemistry. Proposed well LTM-3 will be installed approximately 200 feet east-southeast from the burn pit, along the edge of the gravel pad, to monitor contaminant concentrations and groundwater geochemistry in the vicinity of the proposed air sparging curtain. Existing well MW-152 is proposed for monitoring the groundwater plume within the current anaerobic treatment zone. This location will also serve to monitor the region of the plume downgradient from the proposed air sparging curtain.



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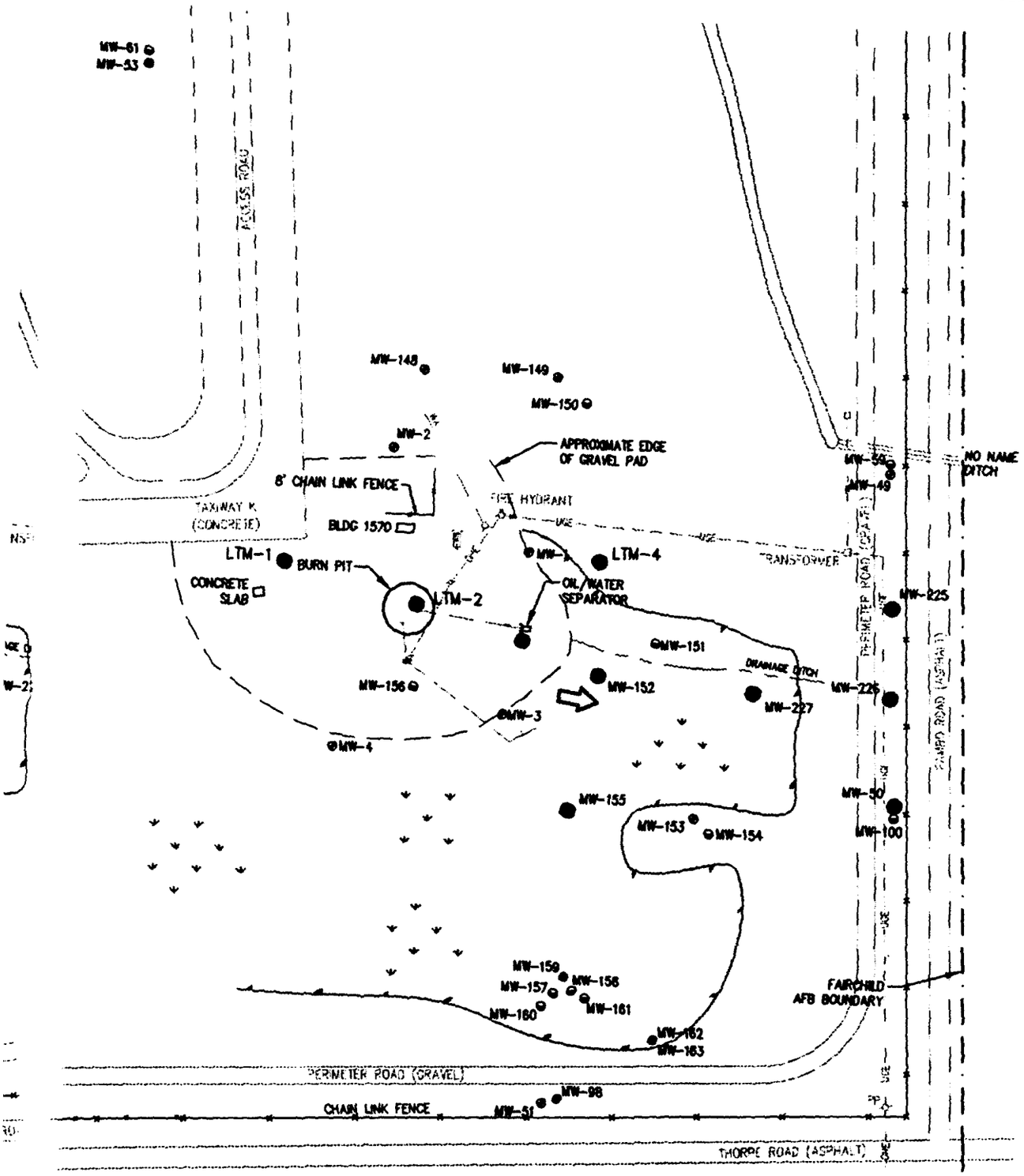
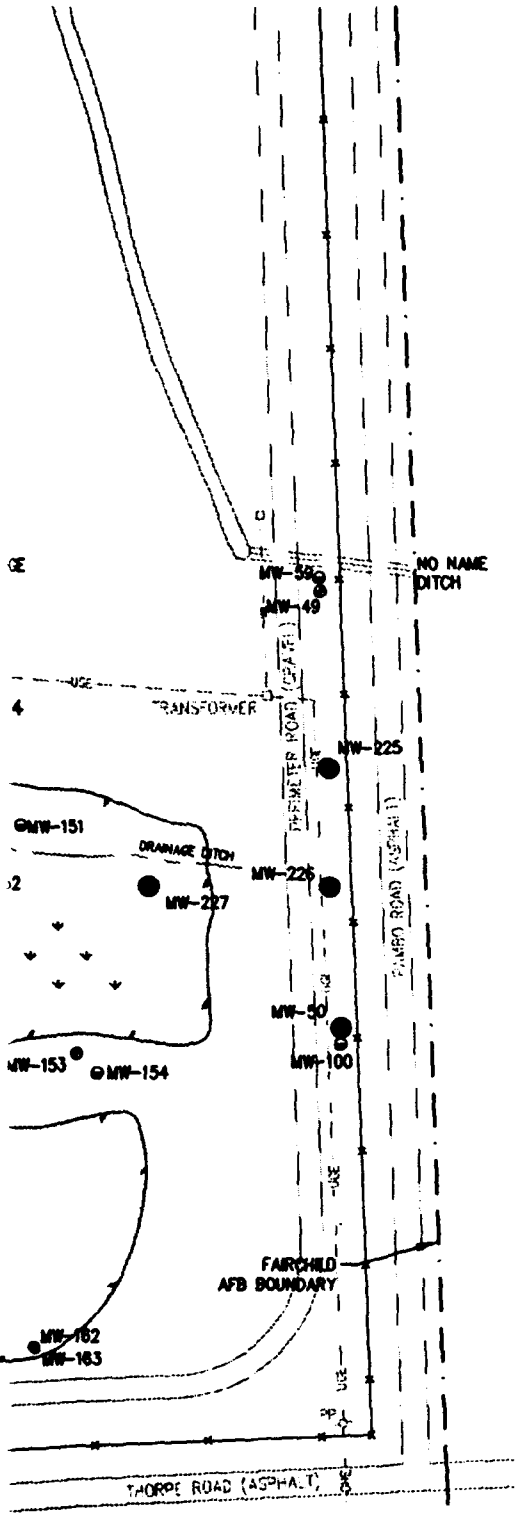

MW-61
MW-53
MW-148
MW-149
MW-150
MW-2
APPROXIMATE EDGE OF GRAVEL PAD
8' CHAIN LINK FENCE
FIRE HYDRANT
TAXIWAY K (CONCRETE)
BLDG 1570
LTM-1
BURN PIT
LTM-4
TRANSFORMER
CONCRETE SLAB
LTM-2
OIL/WATER SEPARATOR
MW-225
MW-151
DRAINAGE DITCH
MW-156
MW-152
MW-226
MW-227
MW-3
MW-4
MW-155
MW-50
MW-153
MW-154
MW-100
MW-159
MW-157
MW-158
MW-160
MW-161
MW-162
MW-163
FAIRCHILD AFB BOUNDARY
PERIMETER ROAD (GRAVEL)
MW-98
CHAIN LINK FENCE
MW-51
THORPE ROAD (ASPHALT)
NO NAME DITCH
MW-49



LEGEND

- SHALLOW MONITORING WELL
- SHALLOW BEDROCK MONITORING WELL
- DEEP BEDROCK MONITORING WELL
- PROPOSED LONG-TERM MONITORING WELL
- APPROXIMATE GROUNDWATER FLOW DIRECTION

N

0 100 200 400

FEET

FIGURE 6.1

PROPOSED LONG-TERM COMPLIANCE MONITORING WELL LOCATIONS

Site FT-1
Remediation by Natural Attenuation
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

Existing well MW-227 is proposed to monitor groundwater conditions near the leading edge of the plume in the aerobic treatment zone.

Two additional wells are proposed for monitoring the lateral extent of plume migration through the anaerobic treatment zone. These wells include existing well MW-155 and proposed well LTM-4, located approximately 200 feet south and 150 north of well MW-152, respectively. Existing well MW-155 is known to be near the southern lateral extent of the plume because a benzene concentration of 1.5 µg/L (total BTEX of 12 µg/L) was detected in a sample collected from this location in April, 1995 (ES&T and MWA, 1995).

The final three wells in the proposed monitoring network include existing wells MW-225, MW-226, and MW-50. These three wells are located approximately 100 feet west of the Base boundary, and will be used to monitor groundwater conditions beyond the projected plume extent. Given an estimated advective groundwater velocity of 72 ft/yr (Section 3.3.4), the travel time from these wells to the Base boundary is approximately 1.4 years. The nearest residential wells are over 1,000 feet east of the Base boundary. The purpose of these three wells is to verify that benzene concentrations exceeding the ROD criterion do not migrate beyond the area under institutional control. Although available evidence strongly suggests that the contaminant plume will not migrate beyond this area at concentrations exceeding the ROD-specified level, these wells are the technical mechanisms used to demonstrate protection of human health and the environment and compliance with regulatory criteria. If regulatory or ROD-specified criteria are exceeded in groundwater samples collected at these downgradient wells, activation of a proposed air sparging curtain at the Base boundary will be considered.

Existing and proposed wells for the proposed long-term groundwater compliance monitoring program will be screened in the same hydrogeologic unit as the contaminant plume. Specifically, they will be screened in the shallow unconsolidated deposits of the surficial aquifer across the water table. Data presented in this report concerning the nature and extent of contamination at the site suggest that a 10-foot screen with approximately 8 feet of screen below the groundwater surface will be sufficient to intercept the benzene plume at this site.

6.3 GROUNDWATER SAMPLING

To ensure that sufficient contaminant removal is occurring at Site FT-1 to meet site-specific compliance goals, groundwater samples will be collected annually from LTM wells to verify that naturally occurring processes are effectively reducing the mass and mobility of BTEX and chlorinated solvent contamination. The sampling and analysis plan also is aimed at confirming that the ROD-specified remediation alternative together with natural attenuation can achieve the site-specific remediation concentration goals. Reductions in toxicity will be implied by mass reduction and by achieving regulatory standards.

This plan proposes annual groundwater compliance sampling at each of the 10 wells in the LTM monitoring network. Annual sampling is considered appropriate for the following reasons:

- Groundwater flow velocity is estimated at only 72 ft/yr;
- The model predicts that the downgradient contaminant extent will not migrate more than 100 feet downgradient of the observed leading edge of the BTEX plume throughout the remediation period; and
- The time to achieve ROD compliance is conservatively estimated at approximately 19 years.

After 10 years, the long-term compliance monitoring program should be reevaluated to determine whether sampling frequency should be maintained, increased, decreased, or discontinued. If the data collected at any time during the monitoring period indicate rapid expansion of the plume or a trend toward increasing contaminant concentrations in the source area, the sampling frequency should be adjusted accordingly, the effectiveness of the selected remedial alternative should be reevaluated, and the need for additional remedial activities at the site should be considered.

All wells in the long-term compliance monitoring program will be sampled and analyzed to determine compliance with chemical-specific compliance goals and to verify the effectiveness of the remediation system at the site. At the beginning of each annual sampling event, water levels will be measured at all site monitoring wells. Groundwater samples from the plume-extent and base-boundary wells will be analyzed for the parameters listed in Tables 6.1 and 6.2, respectively. A site-specific groundwater sampling and analysis plan should be prepared prior to initiating this LTM program.

TABLE 6.1
COMPLIANCE GROUNDWATER MONITORING ANALYTICAL PROTOCOL
PLUME-EXTENT WELLS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous Iron (Fe^{2+})	Colorimetric A3500-Fe D	Field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction	Every Year for 10 years	Collect 100 mL of water in a glass container; acidify with hydrochloric acid per method	Field
Ferrous Iron (Fe^{2+})	Colorimetric Hach 25140-25	Alternate method; field only	Same as above.	Every Year for 10 Years	Collect 100 mL of water in a glass container	Field
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature	Every Year for 10 Years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is an indicator of biodegradation conditions; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Every Year for 10 Years	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct-reading meter	Protocols/Handbook methods[a/]	Aerobic and anaerobic processes are pH-sensitive	Every Year for 10 Years	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct-reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Every Year for 10 Years	Collect 100–250 mL of water in a glass or plastic container	Field
Nitrate (NO_3^{-1})	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	Substrate for microbial respiration if oxygen is depleted	Every Year for 10 Years	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C; analyze within 48 hours	Fixed-base

TABLE 6.1 (CONTINUED)
COMPLIANCE GROUNDWATER MONITORING ANALYTICAL PROTOCOL
PLUME-EXTENT WELLS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Sulfate (SO_4^{2-})	IC method E300 or method SW9056 or Hach SulfaVer 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. Hach method is Photometric	Substrate for anaerobic microbial respiration	Every Year for 10 Years	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for Hach method)
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Every Year for 10 Years	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Alkalinity	HACH Alkalinity test kit model AL AP MG-L	Phenolphtalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same groundwater system and (2) to measure the buffering capacity of groundwater.	Each sampling round	Collect 100 mL of water in glass container	Field
Methane, Ethane, and Ethene	RSKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the USEPA Robert S. Kerr Laboratory	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis).	Every Year for 10 Years	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base

TABLE 6.1 (CONCLUDED)
COMPLIANCE GROUNDWATER MONITORING ANALYTICAL PROTOCOL
PLUME-EXTENT WELLS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020.	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Every Year for 10 Years	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	Fixed-base
Volatile Organics	GS/MS method SW8240	Handbook method	Measured for regulator compliance	Every Year for 10 years	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH < 2	Fixed-base

a/ Protocol methods are presented by Wiedemeier *et al.* (1995). Handbook refers to "AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigation / Feasibility Study (RI/FS).

TABLE 6.2
COMPLIANCE GROUNDWATER MONITORING ANALYTICAL PROTOCOL
BASE-BOUNDARY WELLS
SITE FT-1
REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AFB, WASHINGTON

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature	Every Year for 10 Years	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is an indicator of biodegradation conditions; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Every Year for 10 Years	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct-reading meter	Protocols/Handbook methods[a/]	Aerobic and anaerobic processes are pH-sensitive	Every Year for 10 Years	Collect 100–250 mL of water in a container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct-reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Every Year for 10 Years	Collect 100–250 mL of water in a glass or plastic container	Field
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Every Year for 10 Years	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020.	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Every Year for 10 Years	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	Fixed-base
Volatile Organics	GS/MS method SW8240	Handbook method	Measured for regulator compliance	Every Year for 10 years	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH < 2	Fixed-base

a/ Protocol methods are presented by Wiedemeier *et al.* (1995). Handbook refers to "AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigation / Feasibility Study (RI/FS).

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a TS conducted to evaluate RNA of fuel-hydrocarbon- and CAH-contaminated groundwater in the vicinity of site FT-1 at Fairchild AFB, Washington. It is anticipated that RNA will supplement the engineered remedial actions prescribed in the ROD for the site (HNUS, 1993a). Site-specific geologic, hydrologic, and laboratory analytical data were used to evaluate the occurrence and rates of natural attenuation of BTEX compounds dissolved in groundwater. To perform the RNA demonstration, Parsons ES researchers collected and analyzed groundwater samples from the site and utilized data collected during previous site characterization events.

Two lines of evidence were used to document the occurrence of natural attenuation at FT-1: the documented loss of contaminant mass at the field scale and geochemical evidence. A review of groundwater sampling data obtained from 1989 through 1995 indicates that the dissolved BTEX concentrations have generally decreased downgradient from the source area and the plume has stabilized. Furthermore, rates of biodegradation were estimated from flow path analyses using the methods of Buscheck and Alcantar (1995). Comparison of BTEX, CAH, electron acceptor, and biodegradation byproduct isopleth maps for FT-1 (Section 4) provides strong qualitative geochemical evidence of biodegradation of BTEX and CAHs. Geochemical data strongly suggest that biodegradation of fuel hydrocarbons is occurring at the site via aerobic respiration and the anaerobic processes of denitrification, iron reduction, sulfate reduction, and methanogenesis. In addition, the ratio of TCE and *cis*-1,2-DCE to the daughter product VC suggests that chlorinated solvents in the groundwater are being degraded through reductive dehalogenation.

Site-specific geologic, hydrologic, and laboratory analytical data were used in three conservative numerical groundwater models to simulate the effects of dispersion and biodegradation on the fate and transport of the dissolved BTEX plume. Historical and current site-specific data were used for model development and calibration. Model parameters that could not be obtained from existing site data were estimated using widely accepted literature values for soils similar to those found at the site. Conservative aquifer and contaminant geochemical parameters were used to construct the models for this study, and therefore, the model results presented herein represent worst-case scenarios given the other modeling assumptions regarding source removal.

One of the numerical models, FT-1-sparge, which simulated the ROD-specified remedial actions of bioventing and air sparging, suggested contraction of the BTEX plume coupled with a decrease in dissolved contaminant concentrations over the next 19

years. In contrast, the model that simulated only bioventing with natural attenuation (FT-1-BV) predicted a remediation period of 24 years to achieve ROD and regulatory compliance. The models assumed the same source decay rates to model the long-term effects of bioventing. Implementation of bioventing soil remediation systems have been accompanied by source decay rates averaging over 90 percent per year in vadose zone soils at other Air Force sites. Both models suggested a significant decrease in dissolved BTEX concentrations and a rapid retreat of the BTEX plume when source decay rates were conservatively modeled at 50 percent per year. The remaining model (FT-1-NA) simulated the long-term effects of natural attenuation only on the dissolved BTEX plume. The natural attenuation model suggested that 34 years would be required to remediate the site assuming no engineered remedial actions are implemented at the site.

The results of this study suggest that RNA of BTEX and chlorinated solvent compounds is occurring at FT-1. Benzene was detected at only three locations, all within 250 feet of the burn pit. The estimated rates of biodegradation, when coupled with the effects of sorption, dispersion, and dilution, should be sufficient to reduce and maintain dissolved BTEX and chlorinated solvent concentrations at levels below current regulatory guidelines long before potential downgradient receptors could be adversely affected. Given the possible stabilization and retreat of the dissolved BTEX plume, RNA with LTM is a viable remedial option for BTEX-impacted groundwater at the site. However, due to the ROD cleanup goal for benzene (5 µg/L), RNA with LTM should be used to complement with the ROD-mandated bioventing and air sparging systems.

To verify the results of the analytical modeling effort, and to ensure that RNA is occurring at rates sufficient to protect potential downgradient receptors, groundwater from 10 LTM wells, including 7 plume-extent wells and 3 downgradient base-boundary wells, should be sampled and analyzed for the parameters listed in Tables 6.1 (plume-extent wells) and 6.2 (base-boundary wells). Figure 6.1 shows suggested locations for LTM monitoring wells. These wells should be sampled annually for 10 years. At that time, sampling could cease, decrease in frequency, or continue annually as dictated by the analytical results. If dissolved BTEX or CAH concentrations in groundwater collected from the downgradient Base-boundary wells exceed ROD or regulatory criteria, additional evaluation or corrective action may be necessary at this site.

SECTION 8

REFERENCES

Air Force Center for Environmental Excellence (AFCEE), 1994, Bioventing Performance and Cost Summary. Brooks Air Force Base, p. 8.

Altenschmidt, U. and Fuchs, G., 1991, Anaerobic degradation of toluene in denitrifying *Pseudomonas* sp.: Indication for toluene methylhydroxylation and benzoyl-CoA as central aromatic intermediate: Arch. Microbial., vol. 156, p. 152-158.

Alvarez, P.J.J., and Vogel, T.M., 1991, Substrate interactions of benzene, toluene, and para-xylene during microbial degradation by pure cultures and mixed culture aquifer slurries: Applied Environmental Microbiology, vol. 57, p. 2981-2985.

Alvarez-Cohen, L.M. and McCarty, P.L., 1991a, Effects of toxicity, aeration, and reductant supply on trichloroethylene transformation by a mixed methanotrophic culture: Appl. Environ. Microbiol., vol. 57, no. 1, p. 228-235.

Alvarez-Cohen, L.M., and McCarty, P.L., 1991b, Product toxicity and cometabolic competitive inhibition modeling of chloroform and trichloroethylene transformation by methanotrophic resting cells: Appl. Environ. Microbiol., vol. 57, no. 4, p. 1031-1037.

Anderson, M.P. and Woessner, W.W., 1992, Applied Ground Water Modeling - Simulation of Flow and Advective Transport: Academic Press, New York, New York, 381p.

Arciero, D., Vannelli, T., Logan, M., and Hooper, A.B., 1989, Degradation of trichloroethylene by the ammonia-oxidizing bacterium *Nitrosomonas europaea*: Biochem. Biophys. Res. Commun., vol. 159, p. 640-643.

Atlas, R.M., 1981, Microbial degradation of petroleum hydrocarbons - an environmental perspective: Microbiological Reviews, vol. 45, no. 1, p. 180-209.

Atlas, R.M., 1984, Petroleum Microbiology: Macmillan Publishing Company, New York.

Atlas, R.M., 1988, Microbiology - Fundamentals and Applications: Macmillan Publishing Company, New York.

Baedecker, M.J., Siegel, D.I., Bennett, P.C., Cozzarelli, I.M., 1988, The fate and effects of crude oil in a shallow aquifer: I. The distribution of chemical species and geochemical facies, In: G.E. Mallard, and S.E. Ragone, editors, U.S. Geological Survey Toxic Substances Hydrology Program, Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-42320, p. 29-22.

Baedecker, M.J., and Cozzarelli, I.M., 1991, Geochemical modeling of organic degradation reactions in an Aquifer contaminated with Crude Oil: U.S. Geological Survey Water-Resources Investigations Report 91-4034. Reston, VA. p 627-632.

Ball, H.A., Reinhard, M., and McCarty, P.L., 1991, Biotransformation of monoaromatic hydrocarbons under anoxic conditions, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 458-463.

Barker, J.F., Patrick, G.C., and Major, D., 1987, Natural attenuation of aromatic hydrocarbons in a shallow sand aquifer: Ground Water Monitoring Review, Winter, 1987, p. 64-71.

Bartha, R., 1986, Biotechnology of petroleum pollutant biodegradation: Microbial Ecology, vol. 12, p. 155-172.

Battelle Denver Operations, 1989, Installation Restoration Program, IRP Phase II, Stage I Confirmation/Quantification, Fairchild AFB, Washington. Prepared for the USAF, Occupational and Environmental Health Laboratory, Brooks AFB, Texas.

Bauman, B., 1991, Biodegradation research of the American Petroleum Institute. Presented at: In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation. San Diego, CA. March 19-21, 1991.

Bear, J., 1979, Hydraulics of Groundwater. McGraw-Hill, Inc., New York, New York, 569p.

Beller, H.R. Reinhard, M., and Grbic-Galic, D., 1992, Metabolic byproducts of anaerobic toluene degradation by sulfate-reducing enrichment cultures: Appl. Environ. Microbiol., vol. 58, p. 3192-3195.

Borden, R.C., 1991, Simulation of enhanced in situ biorestoration of petroleum hydrocarbons. In: In Situ bioreclamation: Application and Investigation for Hydrocarbons and contaminated Site Remediation. Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 529-534.

Borden, R.C., and Bedient, P.B., 1986, Transport of dissolved hydrocarbons influenced by oxygen limited biodegradation - theoretical development: Water Resources Research, vol. 22, no. 13, p. 1973-1982.

Bouwer, E.J., 1992, Bioremediation of Subsurface Contaminants, In: Mitchell, R., ed.: Environmental Microbiology. Wiley-Liss, New York, New York.

Bouwer, E.J., 1994, Bioremediation of chlorinated solvents using alternate electron acceptors: In: Handbook of Bioremediation. Lewis Publishers. Boca Raton, FL. 1994.

Bouwer, E.J., Rittman, B.E., and McCarty, P.L., 1981, Anaerobic degradation of halogenated 1- and 2-carbon organic compounds: Environ. Sci. Technol., vol. 15, no. 5, p. 596-599.

Bouwer, E.J. and Wright, J.P., 1988, Transformations of trace halogenated aliphatics in anoxic biofilm columns: J. Contam. Hydrol., vol. 2, p. 155-169.

Bouwer, H., 1989, The Bouwer and Rice slug test - an update: *Ground Water*, 27(3), p. 304-309.

Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: *Water Resources Research*, 12(3), p. 423-428.

Bradley, P.M., and Chapelle, F.H., 1996, Anaerobic mineralization of vinyl chloride in Fe(III)-reducing aquifer sediments: Environmental Science and Technology, vol. 40, p. 2084 - 2086.

Brown, R.A., Dey, J.C. and McFarland, W.E., 1991, Integrated site remediation combining groundwater treatment, soil vapor extraction, and bioremediation, In: *In Situ Bioreclamation: Application and Investigation for Hydrocarbons and* Contaminated Site Remediation. Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 444-449.

Bruce, L., Miller, T., and Hockman, B., 1991, Solubility versus equilibrium saturation of gasoline compounds - a method to estimate fuel/water partition coefficient using solubility or K_{OC}... In, A. Stanley (editor), *NWWAI/API Conference on Petroleum Hydrocarbons in Ground Water:* NWT/API, p. 571-582.

Buscheck, T. E., O'Reilly, K. T., and Nelson, S. N., 1993, Evaluation of INtrinsic Bioremediation at Field Sites: Proceedings, Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Restoration, pp. 367-381. National Ground Water Association/API, Houston, TX.

Buscheck, T. E., and Alcantar, C. M., 1995, Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation. In: Proceedings of the 1995 Battelle International Symposium on In Situ and On-Site Bioreclamation, April 1995.

Chapelle, F.H., 1993, Ground-water Microbiology and Geochemistry. John Wiley and Sons, Inc., New York, NY.

Chapelle, F.H., 1994, Assessing the Efficiency of Intrinsic Bioremediation, *in* Proceedings of the Symposium on Intrinsic Bioremediation of Ground Water, August 30 - September 1, 1994: US Environmental Protection Agency, p. 171.

Chiang, C.Y., Salanitro, H.P., Chai, E.Y., Colthart, H.D., and Klein, C.L., 1989, Aerobic biodegradation of benzene, toluene, and xylene in a sandy aquifer - data analysis and computer modeling: Ground Water, vol. 27, no. 6, p. 823-834.

Cline, D.R., 1969, Groundwater Resources and Related Geology North-central Spokane and Southeastern Stevens Counties of Washington. State of Washington Department of Water Resource Water Supply Bulletin, No. 27.

Cline, P.V., and Delfino, J.J., 1989, Transformation kinetics of 1,1,1-trichloroethane to the stable product 1,1-dichloroethene, In: Biohazards of Drinking Water Treatment. Lewis Publishers, Inc. Chelsea, MI. p. 47-56.

Cozzarelli, I.M., Eganhouse, R.P., and Baedecker, M.J., 1990, Transformation of monoaromatic hydrocarbons to organic acids in anoxic ground water environment: Environmental and Geological Water Science, vol. 16.

Cozzarelli, I.M., Baedecker, M.J., Eganhouse, R.P., 1994, The geochemical evolution of low-molecular-weight organic acids derived from the degradation of petroleum contaminants in groundwater: Geochimica et Cosmochimica Acta, vol. 58, no. 2, p. 863-877.

Davies, J.S., and Westlake, D.W.S., 1979, Crude Oil Utilization by Fungi: Canadian Journal of Microbiology, v. 25, p. 146-156.

Davis, J.W., Klier, N.J., and Carpenter, 1994, Natural biological attenuation of benzene in ground water beneath a manufacturing facility: Ground Water, vol. 32, no. 2, p. 215-226.

De Bruin, W.P., Kotterman, M.J.J., Posthumus, M.A., Schraa, G., and Zehnder, A.J.B., 1992, Complete biological reductive transformation of tetrachloroethene to ethane: Appl. Environ. Microbiol., vol. 58, no. 6, p. 1966 - 2000.

DeStefano, T.D., Gossett, J.M., and Zinder, S.H., 1991, Reductive dechlorination of high concentrations of tetrachloroethene to ethene by an anaerobic enrichment culture in the absence of methanogenesis: Appl. Environ. Microbiol., vol. 57, no. 8, p. 2287-2292.

Domenico, P.A., and Schwartz, F.W., 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, New York, New York, 824p.

EA Engineering, Science, and Technology and Montgomery Watson Americas, Inc. (ES&T and MWA), 1995, Analytical Data Informal Technical Information Report: Long Term Monitoring -- April 1995 Sampling Craig Road Landfill and Priority 1 Sites SW-1, PS-2, PS-8, WW-1, FT-01, Fairchild AFB, Washington. May.

Edwards, E., Wills, L.E., Grbic-Galic, D., and Reinhard, M., 1991, Anaerobic degradation of toluene and xylene--evidence for sulfate as the terminal electron acceptor, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 463-471.

Edwards, E.A., and Grbic-Galic, D., 1992, Complete mineralization of benzene by aquifer microorganisms under strictly anaerobic conditions: Appl. Environ. Microbiol., vol. 58, p. 2663-2666.

Edwards, E.A., Wells, L.E., Reinhard, M., and Grbic-Galic, D., 1992, Anaerobic degradation of toluene and xylene by aquifer microorganisms under sulfate-reducing conditions: Appl. Environ. Microbiol., vol. 58, p. 794-800.

Engineering-Science, Inc. (ES), 1994, Remedial Design Work Plan for Site FT-1, (FT-04), Fire Training Area. Fairchild Air Force Base, Washington. January.

Evans, P.J., Mang, D.T., and Young, L.Y., 1991a, Degradation of toluene and m-xylene and transformation of o-xylene by denitrifying enrichment cultures: Appl. Environ. Microbiol., vol. 57, p.450-454.

Evans, P.J., Mang. D.T., Kim, K.S., and Young, L.Y., 1991b, Anaerobic degradation of toluene by a dentrifying bacterium: Appl. Environ. Microbiol., vol. 57, p. 1139-1145.

Flint, R. I., 1936, Stratified Drift and Deglaciation of Eastern Washington. USGS Bulletin Vol. 47.

Folsom, B.R., Chapman, P.J., and Pritchard, P.H., 1990, Phenol and trichloroethylene degradation by *Pseudomonsa cepacia* G4: Kinetics and interactions between substrates: Appl. Environ. Microbiol., vol. 56, no. 5, p. 1279-1285.

F[illegible]edman, D.L., and Gossett, J.M., 1989, Biological reductive dechlorination of tetrachloroethylene and trichloroethylene to ethylene under methanogenic conditions: Appl. Environ. Microbiol., vol. 55, no. 4, p. 1009-1014.

Gibson, D.T., and Subramanian, V., 1984, Microbial degradation of aromatic hydrocarbons, In: Gibson, D.T., ed: Microbial Degradation of Organic Compounds, Marcel Dekker, Inc., p. 181-252.

Godsey, E.M., 1994, Microbiological and geochemical degradation processes, In: Symposium on Intrinsic Bioremediation in Ground Water. Denver, CO. August 30 - September 1, 1994, p.35-40.

Grbic´-Galic´, D., 1989, Microbial degradation of homocyclic and heterocyclic aromatic hydrocarbons under conditions: Dev. Ind. Microbiol., vol. 30, p. 237-253.

Grbic´-Galic´, D., 1990, Anaerobic microbial transformation of nonoxygenated aromatic and alicyclic compounds in soil, subsurface, and freshwater sediments,

In: Bollag, J.M., and Stotzky, G., eds.: Soil Biochemistry: Marcel Dekker, Inc., New York, NY. p. 117-189.

Grbic´-Galic´, D., and Vogel, T.M., 1987, Transformation of toluene and benzene by mixed methanogenic cultures: Applied and Environmental Microbiology, vol. 53, p. 254-260.

Haag, F., Reinhard, M., and McCarty, P.L., 1991, Degradation of toluene and p-xylene in an anaerobic microcosms: Evidence for sulfate as a terminal electron acceptor: Environ. Toxicol. Chem., vol. 10, p. 1379-1389.

Halliburton NUS (HNUS), 1993a, Installation Restoration Program (IRP) Remedial Investigation Report Priority One Operable Units: LF-01 (SW-1); SD-05 (IS-1); SS-18 (PS-2); SS-28 (PS-6); SS-27 (PS-8); WP-03 (WW-1); FT-04 (FT-1), Fairchild AFB, Washington. February.

HNUS, 1993b. Final Record of Decision On-Base Priority One Operable Units. Fairchild Air Force Base, Washington. July.

Harker, A.R., and Kim, Y., 1990, Trichloroethylene degradation by two independent aromatic-degrading pathways in *Alcaligenes eutrophus* JMP134: Appl. Environ. Microbiol., vol. 56, no. 4, p. 1179-1181.

Hartmans, S., and de Bont, J.A.M., 1992, Aerobic vinyl chloride metabolism in Mycobacterium aurum Li: Appl. Environ. Microbiol., vol. 58, no. 4, p. 1220-1226.

Henry, S.M., 1991, Transformation of Trichloroethylene by Methanotrophs from a Groundwater Aquifer. Ph.D. Thesis. Stanford University. Palo Alto, California.

Herrington, R.T., Swanson, M.A., Wiedemeier, T.H., 1996, Intrinsic Remediation in Low Temperature Groundwater Environments - Case Studies From Two Northern Air Force Bases, Sixth West Coast Conference on Contaminated Soils and Groundwater, March 11-14, 1996, Part III.

Hutchins, S.R., 1991, Biodegradation of monoaromatic hydrocarbons by aquifer microorganisms using oxygen, nitrate, or nitrous oxide as the terminal electron acceptor: Appl. Environ. Microbiol., v. 57, p. 2403-2407.

Hutchins, S.R., and Wilson, J.T., 1991, Laboratory and field studies on BTEX biodegradation in a fuel-contaminated aquifer under denitrifying conditions, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 157-172.

Hutchins, S.R., Sewell, G.W., Sewell, D.A., Kovacs, D.A., and Smith, G.A., 1991a, Biodegradation of monoaromatic hydrocarbons by aquifer microorganisms using oxygen, nitrate, or nitrous oxide as the terminal electron acceptor: Environ. Sci. Technol., vol. 25, no. 1, p. 68-76.

Hutchins, S.R., Downs, W.C., Smith, G.B., Smith, J.T., Wilson, D.J., Hendrix, D.J., Fine, D.D., Kovacs, D.A., Douglass, R.H., and Blaha, F.A., 1991b, Nitrate for Biorestoration of an Aquifer Contaminated with Jet Fuel. U.S. Environmental Protection Agency. Robert S. Kerr Environmental Research Laboratory. Ada, Oklahoma. epa/600/2-91/009. April, 1991.

ICF Technology, Inc., 1995. Long Term Monitoring Report for Priority One Sites SW-1 (LF-1), PS-2 (SS-18), and PS-8 (SS-26) at Fairchild Air Force Base, Washington. July.

Isnard, S., and Lambert, S., 1988, Estimating Bioconcentration Factors from Octanol-Water Partition Coefficient and Aqueous Solubility: Chemosphere, vol. 17, no. 1, p. 21-34.

Jamison, V.W., Raymond, R.L., and Hudson, J.O. Jr., 1975, Biodegredation of high-octane gasoline in ground water: Developments in Industrial Microbiology, vol. 16.

JRB Associates, 1985. Installation Restoration Program IRP Phase I Records Search, 92nd Bombardment Wing (Heavy) Fairchild AFB, Washington. Prepared for the USAF, Occupational and Environmental Health Laboratory, Brooks AFB, Texas.

Klier, N.J., West, R.J., and Donberg, P.A., 1996, Aerobic biodegradation of dichloroethylenes in surface and subsurface soils: Paper submitted to Chemosphere, May 1996.

Konikow, L.F., 1978, Calibration of ground-water models, *in* Verification of Mathematical and Physical Models in Hydraulic Engineering: American Society of Civil Engineers, New York, pp. 87 - 93.

Konikow, L.F., and Bredehoeft, J.D., 1978, Computer model of two-dimensional solute transport and dispersion in ground water: United States Geological Survey, Techniques of Water Resources Investigations of the United States Geological Survey, Book 7, Chapter C2, 90 p.

Leahy, J.G., and Colewell, R.R., 1990, Microbial degradation of hydrocarbons in the environment: Microbiolgical Reviews, vol. 53, no. 3, p. 305-315.

Lee, M.D., 1988, Biorestoration of Aquifers Contaminated with Organic Compounds: CRC Critical Reviews in Environmental Control. vol. 18. p. 29-89.

Little, C.D., Palumbo, A.V., Herbes, S.E., Lidstrom, M.E., Tyndall, R.L., and Gilmer, P.J., 1988, Trichloroethylene biodegradation by a methane-oxidizing bacterium: Appl. Environ. Microbiol., vol. 54, no. 4, p. 951-956.

Lovley, D.R., Baedecker, M.J., Lonergan, D.J., Cozzarelli, I.M., Phillips, E.J.P., and Siegel, D.I., 1989, Oxidation of aromatic contaminants coupled to microbial iron reduction: Nature, vol. 339, p. 297-299.

Lovley, D.R., and Phillips, E.J.P., 1988, Novel mode of microbial energy metabolism: organic carbon oxidation coupled to dissimilatory reduction of iron

or manganese: Applied and Environmental Microbiology, v. 54, no. 6, p. 1472 - 1480.

Lovley, D.R., Phillips, E.J.P., and Lonergan, D.J., 1991, Enzymatic versus nonenzymatic mechanisms for Fe(III) reduction in aquatic sediments: Environmental Science and Technology, v. 26, no. 6, p. 1062 - 1067.

Malone, D.R., Kao, C.M., and Borden, R.C., 1993, Dissolution and biorestoration of nonaqueous phase hydrocarbons - models development and laboratory evaluation: Water Resources Research, vol. 29, no. 7, p. 2003-2213.

Mayer, K.P., Grbic-Galic, D., Semprini, L., and McCarty, P.L., 1988, Degradation of trichloroethylene by methanotrophic bacteria in a laboratory column of saturated aquifer material: Wat. Sci. Tech. (Great Britain), vol. 20, no. 11/12, p. 175-178.

McCarty, P.L., Roberts, P.V., Reinhard, M., and Hopkins, G., 1992, Movement and transformations of halogenated aliphatic compounds in natural systems, In: Fate of Pesticides and Chemicals in the Environment. Ed., J.L. Schnoor. John Wiley & Sons, Inc. New York, New York. p. 191-209.

McCarty, P.L., and Semprini, L., 1994, Ground-Water Treatment for Chlorinated Solvents, In: Handbook of Bioremediation. Lewis Publishers, Boca Raton, FL. 1994.

Miller, R.E., and Guengerich, F.P., 1982, Oxidation of trichloroethylene by liver microsomal cytochrome P-450: Evidence for chlorine migration in a transition state no involving trichloroethylene oxide: Biochemistry, vol. 21, p. 1090-1097.

Montgomery, J.H., and Welkom, L.M., 1990, Groundwater Chemicals Desk Reference, Lewis Publishers, 640 p.

Murray, W.D. and Richardson, M., 1993, Progress toward the biological treatment of C_1 and C_2 halogenated hydrocarbons: Critical Reviews in Environmental Science and Technology, v. 23, no. 3, p. 195-217.

Nelson, M.J.K., Montgomery, S.O., O'Neille, E.J., and Pritchard, P.H., 1986, Aerobic metabolism of trichloroethylene by a bacterial isolate: Appl. Environ. Microbiol., vol. 52, no. 2, p. 949-954.

Parsons Engineering Science, Inc. (Parsons), 1994, Baseline Data Bioventing and Air Sparging Treatability Test Letter Report Site FT-1, Fire Training Facility. Fairchild Air Force Base, Washington. December.

Parsons Engineering Science (Parsons ES), 1995, Work Plan for a Treatibility Study to Evaluate Intrinsic Remediation of Groundwater at Site FT-1, Fairchild AFB, Washington, October.

Parsons ES, 1996, Bioventing and Air Sparging Pilot Tests Summary Report for Site FT-1, Fairchild AFB, Washington, January.

Reinhard, M., Goodman, N.L., and Barker, J.F., 1984, Occurrence and distribution of organic chemicals in two landfill leachate plumes: Environ. Sci. Technol., vol. 18, no. 12, p. 953-961.

Rifai, H.S., Bedient, P.B., Wilson, J.T., Miller, K.M., and Armstrong, J.M., 1988, Biodegredation modeling at aviation fuel spill site: Journal of Environmental Engineering, vol. 114, no. 5, p. 1007-1029.

Stauffer, T.B., Antworth, T.B., Boggs, J.M., and MacIntyre, W.G., 1994, A Natural Gradient Tracer Experiment in a Heterogeneous Aquifer with Measured In Situ Biodegradation Rates: A Case for Natural Attenuation, *in* Proceedings of the Symposium on Intrinsic Bioremediation of Ground Water, August 30 - September 1, 1994: US Environmental Protection Agency, p. 73 - 84.

Stumm, W. and Morgan, J.J., 1981, Aquatic Chemistry. John Wiley & Sons, New York, NY.

Thierrin, J., Davis, G.B., Barber, C., Patterson, B.M., Pribac, F., Power, T.R., and Lambert, M., 1992, Natural degradation rates of BTEX compounds and naphthalene in a sulfate-reducing ground water environment, In: In-Situ Bioremediation Symposium "92". Niagara-on-the-Lake, Ontario, Canada. September 20-24, 1992: In Press.

US Geological Survey (USGS), 1973a, USGS 1973b, USGS 1986a, USGS 1986b, 7.5 Minute Quadrangle Map of the Deep Creek Quadrangle, Washington.

Vogel, T.M., 1994, Natural bioremediation of chlorinated solvents, In: Handbook of Bioremediation. *Lewis Publishers, Boca Raton, FL.* 1994.

Vogel, T.M., Criddle, C.S., and McCarty, P.L., 1987, Transformations of Halogenated aliphatic compounds: Environmental Science and Technology, vol. 21, no. 8, p. 722-736.

Vogel, T.M., and McCarty, P.L., 1985, Biotransformation of tetrachloroethylene to trichloroethylene, dichloroethylene, vinyl chloride, and carbon dioxide under methanogenic conditions: Applied Environmental Microbiology, v. 49, no. 5, pp. 1080-1083.

Vroblesky, D.A., and Chapelle, F.H., 1994, Temporal and spatial changes of terminal electron-accepting processes in a petroleum hydrocarbon-contaminated aquifer and the significance for contaminant biodegradation: Water Resources Research, v. 30, no. 5, p. 1561-1570.

Walton, W.C., 1988, Practical Aspects of Ground Water Modeling. National Water Well Association, Worthington, Ohio, 587 p.

Wiedemeier, T.H., Wilson, J.T., Kampbell, D.H., Miller, R.N., and Hansen, J.E., 1995, *Technical Protocol for Implementing Intrinsic Remediation with Long-term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Ground Water.* Prepared by the Air Force Center for Environmental Excellence.

Wilson, J.T., and Wilson, B.H., 1985, Biotransformation of trichloroethylene in soil: Appl. Environ. Microbiol., vol. 49, no. 1, p. 242-243.

Wilson, B.H., Smith, G.B., and Rees, J.F., 1986, Biotransformations of Selected Alkylbenzenes and Halogenated Aliphatic Hydrocarbons in Methanogenic Aquifer Material: A Microcosm Study: Environmental Science and Technology, 20(10):997-1002.

Wilson, B.H., Bledsoe, B., and Kampbell, D., 1987, Biological processes occurring at an aviation gasoline spill site, In: R.C. Averett and D.M. McKnight editors, Chemical Quality of Water and the Hydrologic Cycle. Lewis Publishers, Chelsea, Michigan, p.125-137.

Wilson, B.H., Wilson, J.T., Kampbell, D.H., Bledsoe, B.E., and Armstrong, J.M., 1990, Biotransformation of Monoaromatic and Chlorinated Hydrocarbons at an Aviation Gasoline Spill Site: Geomicrobiology Journal, 8:225-240.

Wilson, B.H., Wilson, J.T., Kampbell, D.H., and Bledsoe, B.E., 1994, Traverse City: Geochemistry and Intrinsic Bioremediation of BTEX Compounds, In: Proceedings of the Symposium on Intrinsic Bioremediation of Ground Water. August 30 - September 1, 1994. US Environmental Protection Agency, p. 94 - 102.

Young, L.Y., 1984, Anaerobic degradation of aromatic compounds, In: Gibson, D.R., ed.: Microbial Degradation of Aromatic Compounds. Marcel-Dekker, New York.

APPENDIX A

GEOLOGIC LOGS, MONITORING POINT COMPLETION RECORDS AND SLUG TEST RESULTS

APPENDIX A.1

GEOLOGIC LOGS

GEOLOGIC BORING LOG

BORING NO.:	ES-SB-1(5) MV MP-30 1345 (5)	CONTRACTOR:	PARSONS ES	DATE SPUD:	10/31/95
CLIENT:	AGREE	RIG TYPE:	GEOPROBE	DATE CMPL.:	10/31/95
JOB NO.:	722450 18	DRLG METHOD:	DIRECT PUSH	ELEVATION:	2405.0
LOCATION:	FAIRCHILD	BORING DIA.:	2"	TEMP:	40°
GEOLOGIST:	MV & AJR	DRLG FLUID:	NONE	WEATHER:	Clear
COMENTS:	BACKGROUND				

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			GRAVELY SAND, GRAY, FILL								
				SILTY SAND w/ SOME GRAVEL, ORGANICS, BROWN/BLACK		90% 14	TOC @4					
	5	▼		GRAVELLY SAND, coarsening with depth, isolated BASALT FRAGMENTS - BROWN		90%			0			
				SAA		8	TOC @8		0			
	10					70%						
				SAA		12						
	15			No Recovery - Rock Blocked SAMPLER		0% 16						
				↑ Refusal @ ≈ 16' bgs								
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Site FT-1
Intrinsic Remediation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

GEOLOGIC BORING LOG

BORING NO.: ES-MP-25 CONTRACTOR: PARSONS ES DATE SPUD: 10/31/96
CLIENT: AFCEE RIG TYPE: GEOPROBE DATE CMPL.: 10/31/96
JOB NO.: 722450.1B DRLG METHOD: POSH ELEVATION: 2399.7
LOCATION: FAIRCHILD BORING DIA.: 2" TEMP: 35°
GEOLOGIST: MV & AJR DRLG FLUID: NONE WEATHER: Clear
COMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Black, Top Soil, SAND								
2.1				Fine to med, Tan, Brown SAND,		100%						
	5	▼		Saturated @ 5' No odor		4			0			
7.2				Weathered Bedrock, - CLAYEY WITH BASALT FRAGMENTS		8			0			
	10					80% 10.2						
				Bottom - REFUSAL								
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level encountered

GEOLOGIC BORING LOG

Site FT-1
Intrinsic Remediation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

GEOLOGIC BORING LOG

BORING NO.: FS-SB-2 CONTRACTOR: PARSONS ES DATE SPUD: 10/31/95
CLIENT: AFCEE RIG TYPE: GEOPROBE DATE CMPL.: 10/31/95
JOB NO.: 722450 19020 DRLG METHOD: GeoProbe ELEVATION: 2464.3
LOCATION: FT-01 BORING DIA.: 2" TEMP: 32°
GEOLOGIST: TR / MV DRLG FLUID: None WEATHER: Clear, 10 mph wind
COMENTS:

Elev (ft)	Depth (ft)	Profile	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			GRAVELY SAND, FILL BLACK, GRAY,		100%						
				Sand, Silty Brown/Black w/ 2" lense of greenish medium Sand @ ~5' bgs		4			330			
	5	▼				80%			297			
				Coarse, Sand, GRAY, Strong odor, wet		8			320			
	10			SAA ↓ BOTTOM @ 12'		60%			157			
						12						
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Site FT-1
Intrinsic Remediation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

GEOLOGIC BORING LOG

BORING NO.: ES-SB-3 CONTRACTOR: Parsons ES DATE SPUD: 11/8/95
CLIENT: AFCEE RIG TYPE: Geoprobe DATE CMPL.: 11/8/95
JOB NO.: 722450.18 DRLG METHOD: Direct Push ELEVATION: 2402.4
LOCATION: Fairchild BORING DIA.: 2" TEMP: 40°
GEOLOGIST: MW & AIR DRLG FLUID: None WEATHER: Cloudy
COMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			BLACK, SAND & GRAVEL FILL								
				Fine - medium gray Sand, Slight odor		90%			17			
	5	▼		Sand, with Some Gravel, coarse grained, wet @ 5', Strong odor, fuel Staining		4			387			
						90%						
						8			330			
				Bottom @ 8'								
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

GEOLOGIC BORING LOG

Site FT-1
Intrinsic Remediation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

GEOLOGIC BORING LOG

BORING NO.: ES-SB-4 CONTRACTOR: PARSONS ES DATE SPUD: 11/8/95
CLIENT: AFCEE RIG TYPE: GeoProbe DATE CMPL.: 11/8/95
JOB NO.: 722450.1B DRLG METHOD: Direct Push ELEVATION: 2404.2
LOCATION: FAIRHILD BORING DIA.: 2" TEMP: 40°
GEOLOGIST: MV & AJR DRLG FLUID: None WEATHER: Cloudy
COMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			Blk, sand and GRAVEL, Slight odor								
2.5'						100%			13			
				Fine - medium Sand, GRAY, Moderate odor					151			
4.8	5	▼				4						
				WET, Coarse Sand, Some GRAVEL, STRONG odor		90%						
									331			
				Bottom @ 8		8						
	10											
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

FIGURE 3.3

GEOLOGIC BORING LOG

Site FT-1
Intrinsic Remediation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

APPENDIX A.2

MONITORING POINT COMPLETION RECORDS

MONITORING POINT INSTALLATION RECORD

JOB NAME Fairchild - FT-1 MONITORING POINT NUMBER MP-1D

JOB NUMBER 722450 INSTALLATION DATE 11/7/95 LOCATION FT-1

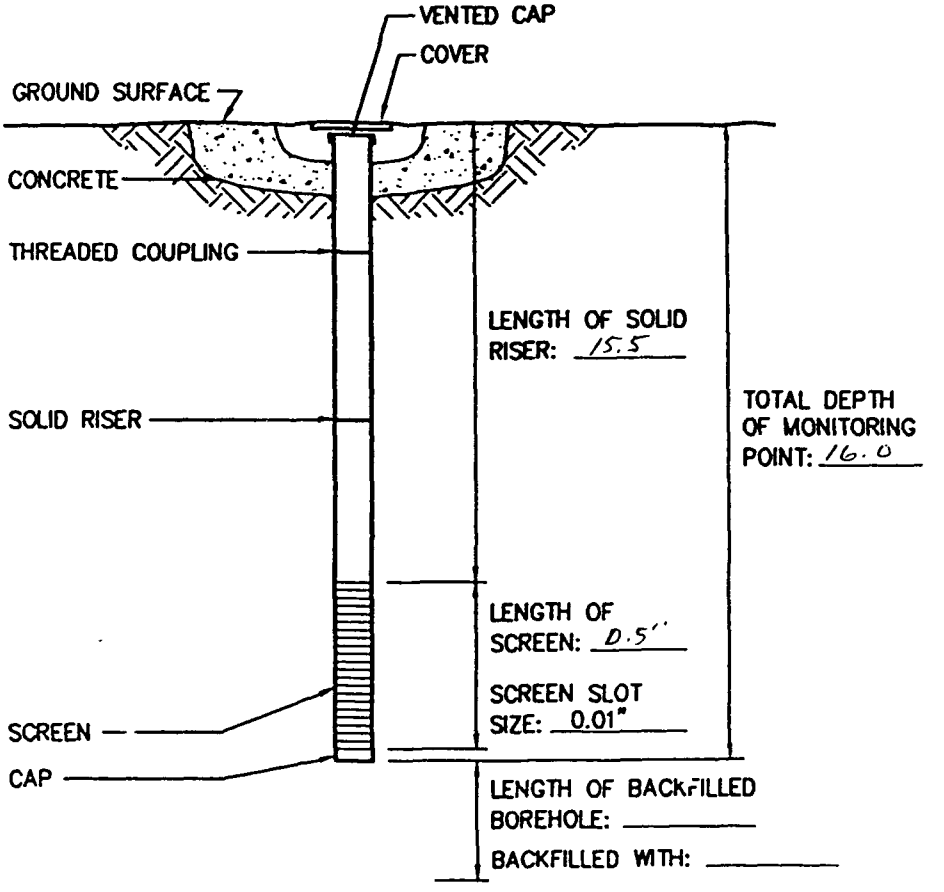
DATUM ELEVATION none GROUND SURFACE ELEVATION 2400.6

DATUM FOR WATER LEVEL MEASUREMENT none

SCREEN DIAMETER & MATERIAL 0.5" 0.375" wire mesh SLOT SIZE 0.037"

RISER DIAMETER & MATERIAL 0.375" Teflon lined HDPE BOREHOLE DIAMETER 0.5"

CONE PENETROMETER CONTRACTOR Parsons ES ES REPRESENTATIVE MV & AJR



(NOT TO SCALE)

STABILIZED WATER LEVEL NM FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 16 FEET BELOW DATUM.

GROUND SURFACE 2400.6 FEET

MONITORING POINT INSTALLATION RECORD

Site FT-1
Intrinsic Remediation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME FAIRCHILD MONITORING POINT NUMBER MP-2S

JOB NUMBER 722450.18 INSTALLATION DATE 10/31/95 LOCATION FT-1

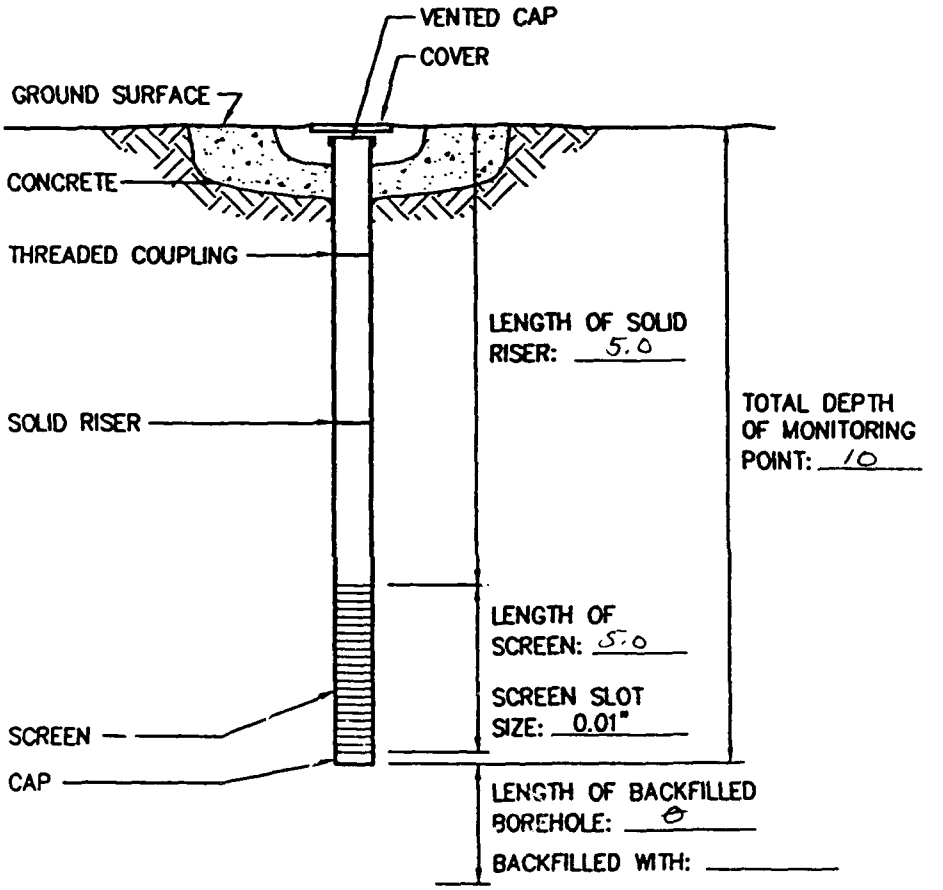
DATUM ELEVATION _____ GROUND SURFACE ELEVATION 2405.0

DATUM FOR WATER LEVEL MEASUREMENT Top of CASING

SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010

RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER ~~0.0~~ MW 0.2.0

CONE PENETROMETER CONTRACTOR PARSONS ES ES REPRESENTATIVE MW & AJR



(NOT TO SCALE)

STABILIZED WATER LEVEL 5.90 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 10.0 FEET BELOW DATUM.

GROUND SURFACE 2405.1 FEET

MONITORING POINT INSTALLATION RECORD

Site FT-1
Intrinsic Remediation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME FAIRCHILD AFB MONITORING POINT NUMBER MP-3D

JOB NUMBER 722450.1B INSTALLATION DATE 10/31/95 LOCATION FT-1

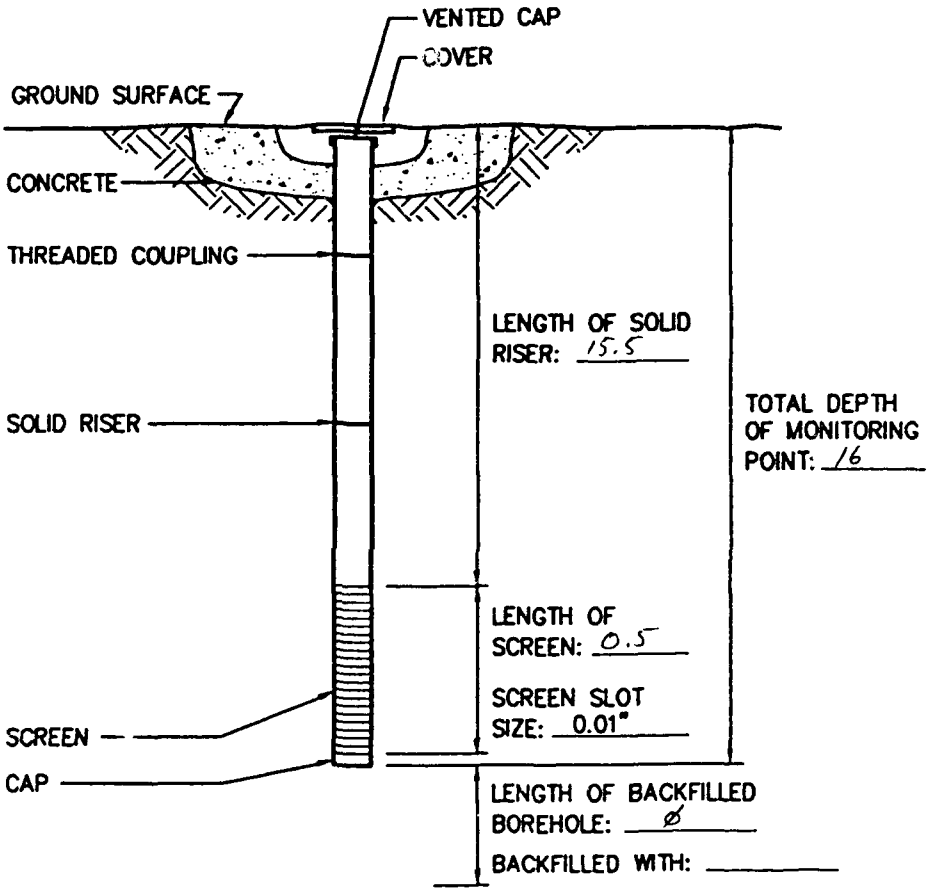
DATUM ELEVATION 2405.0 GROUND SURFACE ELEVATION 2405.0

DATUM FOR WATER LEVEL MEASUREMENT GROUND SURFACE

SCREEN DIAMETER & MATERIAL 0.375" WIRE MESH SLOT SIZE 0.037"

RISER DIAMETER & MATERIAL 0.375" TEFLON LINED HDPE BOREHOLE DIAMETER 0.5"

CONE PENETROMETER CONTRACTOR ~~AFB~~ PARSONS ES ES REPRESENTATIVE MV & AJR



(NOT TO SCALE)

STABILIZED WATER LEVEL NM FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 16 FEET BELOW DATUM.

GROUND SURFACE 2405.0 FEET

MONITORING POINT INSTALLATION RECORD

Site FT-1
Intrinsic Remediation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME FAIRCHILD AFB MONITORING POINT NUMBER MP-4S

JOB NUMBER 722450.18 INSTALLATION DATE 10/31/96 LOCATION FT-1

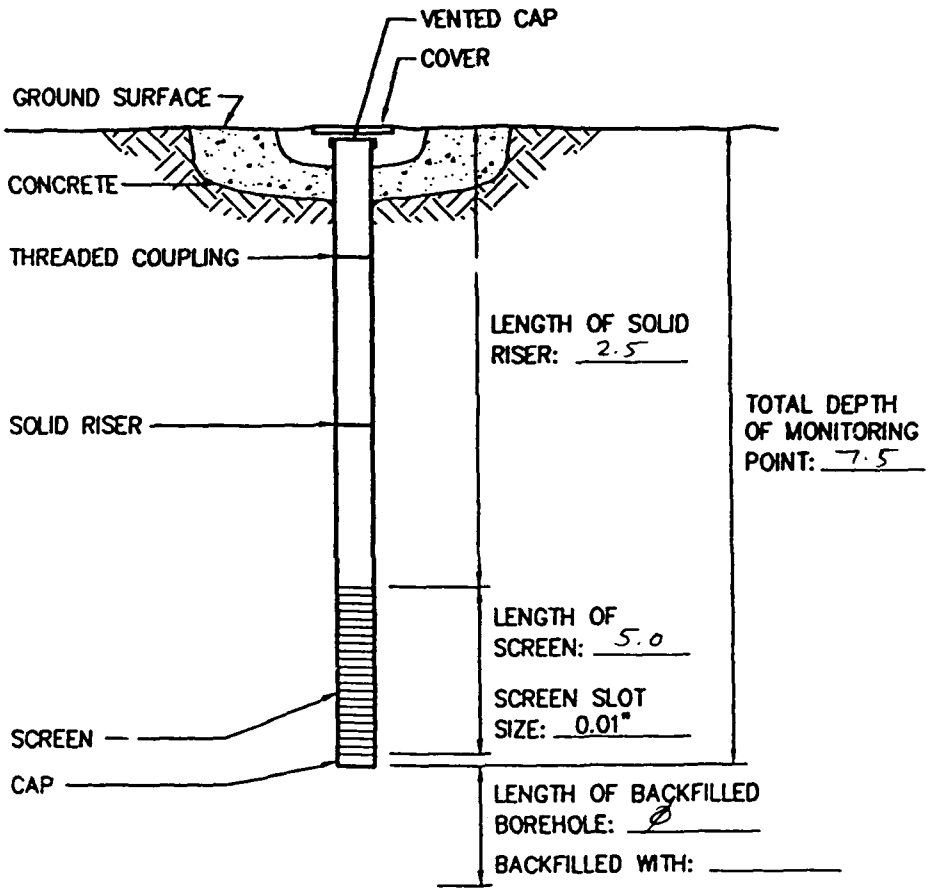
DATUM ELEVATION 2399.7 GROUND SURFACE ELEVATION 2399.7

DATUM FOR WATER LEVEL MEASUREMENT Ground Surface

SCREEN DIAMETER & MATERIAL 0.5" PVC SLOT SIZE 0.010

RISER DIAMETER & MATERIAL 0.5" PVC BOREHOLE DIAMETER 2.0

CONE PENETROMETER CONTRACTOR Parsons ES ES REPRESENTATIVE MV & AJR



(NOT TO SCALE)

STABILIZED WATER LEVEL 3.23 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 7.5 FEET BELOW DATUM.

GROUND SURFACE 2399.7 FEET

MONITORING POINT INSTALLATION RECORD

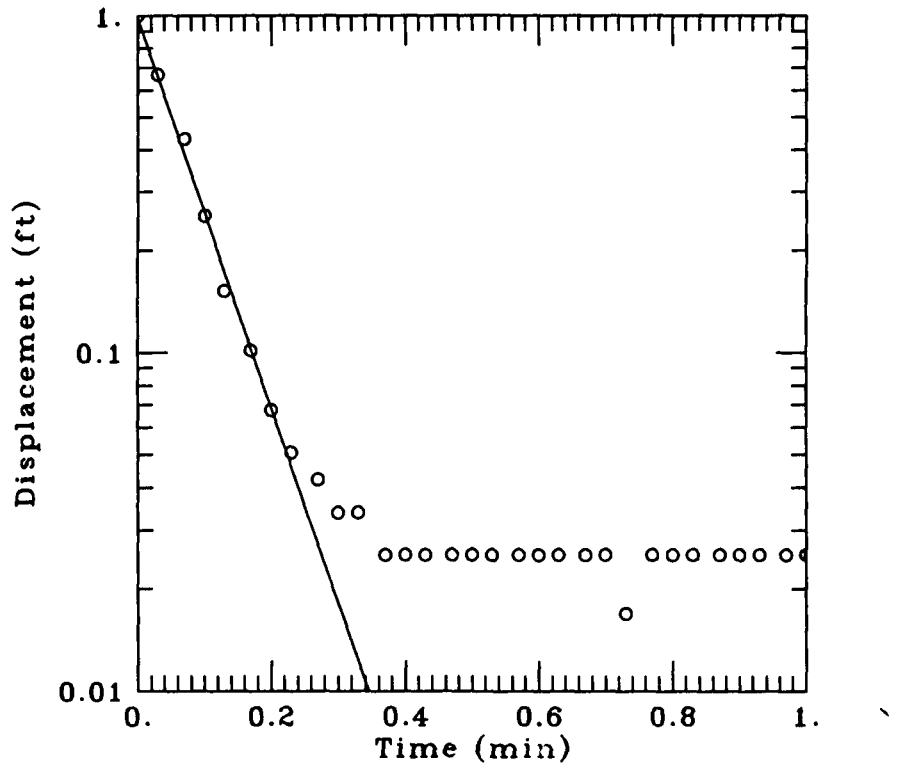
Site FT-1
Intrinsic Remediation TS
Fairchild AFB, Washington

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

APPENDIX A.3

SLUG TEST RESULTS

FT-01, Well MW-1 (Falling Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

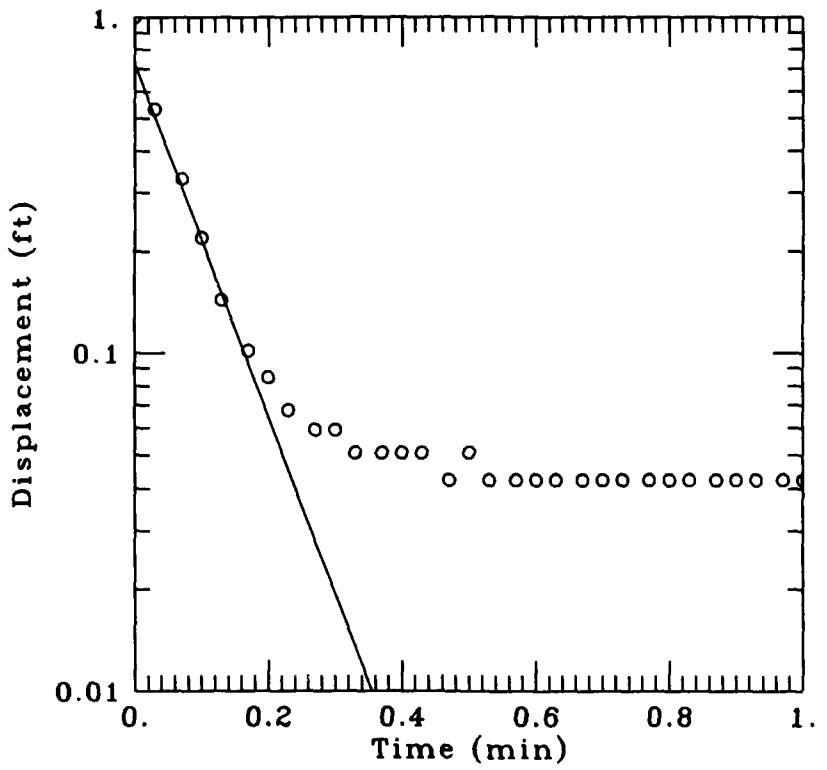
ESTIMATED PARAMETERS:
K = 0.0136 ft/min
y0 = 0.9822 ft

TEST DATA:
H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5.5 ft
b = 9 ft
H = 4 ft

FT-01, Well MW-1 Falling Head 1

Time	Head Change	Unit
0	2.163	1
0.03	0.6675	1
0.07	0.4309	1
0.1	0.2535	1
0.13	0.1521	1
0.17	0.1014	1
0.2	0.0676	1
0.23	0.0507	1
0.27	0.0422	1
0.3	0.0338	1
0.33	0.0338	1
0.37	0.0253	1
0.4	0.0253	1
0.43	0.0253	1
0.47	0.0253	1
0.5	0.0253	1
0.53	0.0253	1
0.57	0.0253	1
0.6	0.0253	1
0.63	0.0253	1
0.67	0.0253	1
0.7	0.0253	1
0.73	0.0169	1
0.77	0.0253	1
0.8	0.0253	1
0.83	0.0253	1
0.87	0.0253	1
0.9	0.0253	1
0.93	0.0253	1
0.97	0.0253	1
1	0.0253	1
1.03	0.0253	1
1.07	0.0253	1
1.1	0.0253	1
1.13	0.0253	1
1.17	0.0253	1
1.2	0.0253	1
1.23	0.0253	1
1.27	0.0253	1
1.3	0.0253	1
1.33	0.0253	1
1.37	0.0253	1
1.4	0.0253	1
1.43	0.0253	1

FT-01, Well MW-1 (Falling Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined
SOLUTION METHOD
Bouwer-Rice

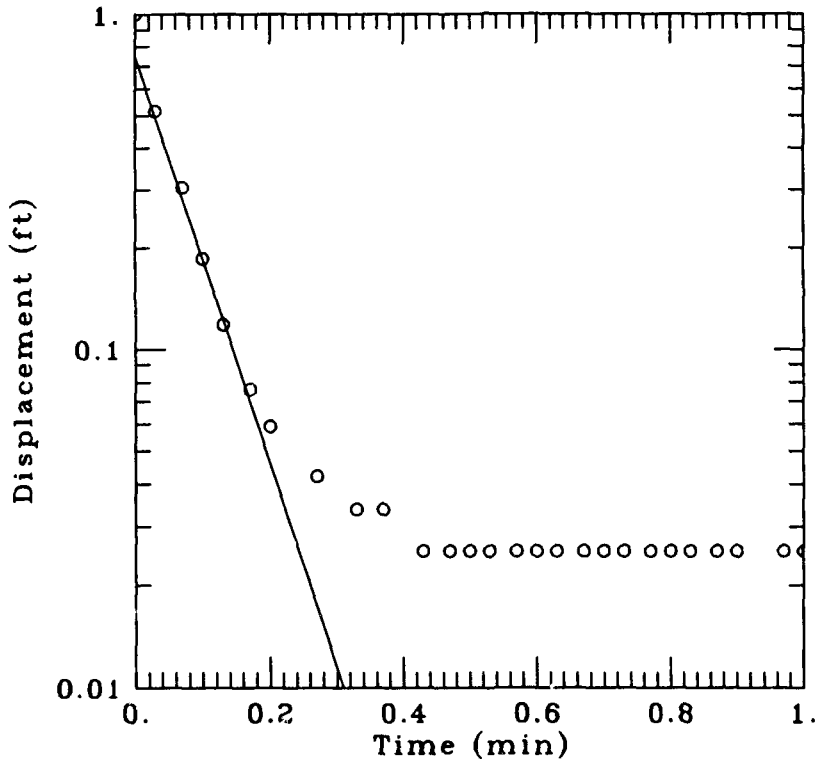
ESTIMATED PARAMETERS
K = 0.01237 ft/min
y0 = 0.7268 ft

TEST DATA:
H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5.5 ft
b = 9 ft
H = 4 ft

FT-01, Well MW-1 Falling Head 2

Time	Head Change	Unit
0	1.0224	1
0.03	0.5324	1
0.07	0.3296	1
0.1	0.2197	1
0.13	0.1437	1
0.17	0.1014	1
0.2	0.0845	1
0.23	0.0676	1
0.27	0.0592	1
0.3	0.0592	1
0.33	0.0507	1
0.37	0.0507	1
0.4	0.0507	1
0.43	0.0507	1
0.47	0.0423	1
0.5	0.0507	1
0.53	0.0423	1
0.57	0.0423	1
0.6	0.0423	1
0.63	0.0423	1
0.67	0.0423	1
0.7	0.0423	1
0.73	0.0423	1
0.77	0.0423	1
0.8	0.0423	1
0.83	0.0423	1
0.87	0.0423	1
0.9	0.0423	1
0.93	0.0423	1
0.97	0.0423	1
1	0.0423	1
1.03	0.0423	1
1.07	0.0423	1
1.1	0.0423	1
1.13	0.0423	1
1.17	0.0423	1
1.2	0.0423	1
1.23	0.0423	1
1.27	0.0423	1
1.3	0.0423	1
1.33	0.0423	1
1.37	0.0423	1
1.4	0.0423	1
1.43	0.0423	1
1.47	0.0423	1
1.5	0.0423	1
1.53	0.0423	1

FT-01, Well MW-1 (Rising Head Test 1)



DATA SET

10/09/97

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

K = 0.01427 ft/min
y0 = 0.7512 ft

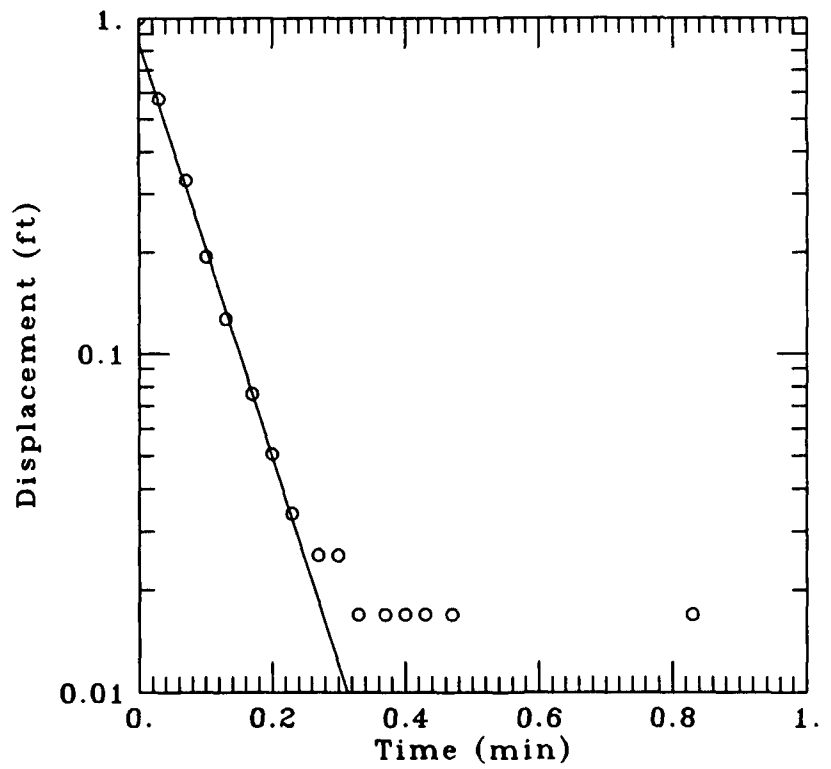
TEST DATA

H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5.5 ft
b = 9 ft
H = 4 ft

FT-01, Well MW-1 Rising Head 1

Time	Head Change	Unit
0	0.9125	1
0.03	0.5154	1
0.07	0.3041	1
0.1	0.1858	1
0.13	0.1182	1
0.17	0.076	1
0.2	0.0591	1
0.23	0.0506	1
0.27	0.0422	1
0.3	0.0337	1
0.33	0.0337	1
0.37	0.0337	1
0.4	0.0253	1
0.43	0.0253	1
0.47	0.0253	1
0.5	0.0253	1
0.53	0.0253	1
0.57	0.0253	1
0.6	0.0253	1
0.63	0.0253	1
0.67	0.0253	1
0.7	0.0253	1
0.73	0.0253	1
0.77	0.0253	1
0.8	0.0253	1
0.83	0.0253	1
0.87	0.0253	1
0.9	0.0253	1
0.93	0.0169	1
0.97	0.0253	1
1	0.0253	1
1.03	0.0169	1
1.07	0.0169	1
1.1	0.0253	1
1.13	0.0169	1
1.17	0.0169	1
1.2	0.0169	1
1.23	0.0169	1
1.27	0.0169	1
1.3	0.0253	1
1.33	0.0169	1
1.37	0.0253	1
1.4	0.0169	1
1.43	0.0169	1
1.47	0.0169	1
1.5	0.0169	1

FT-01, Well MW-1 (Rising Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS

K = 0.01452 ft/min
y0 = 0.8502 ft

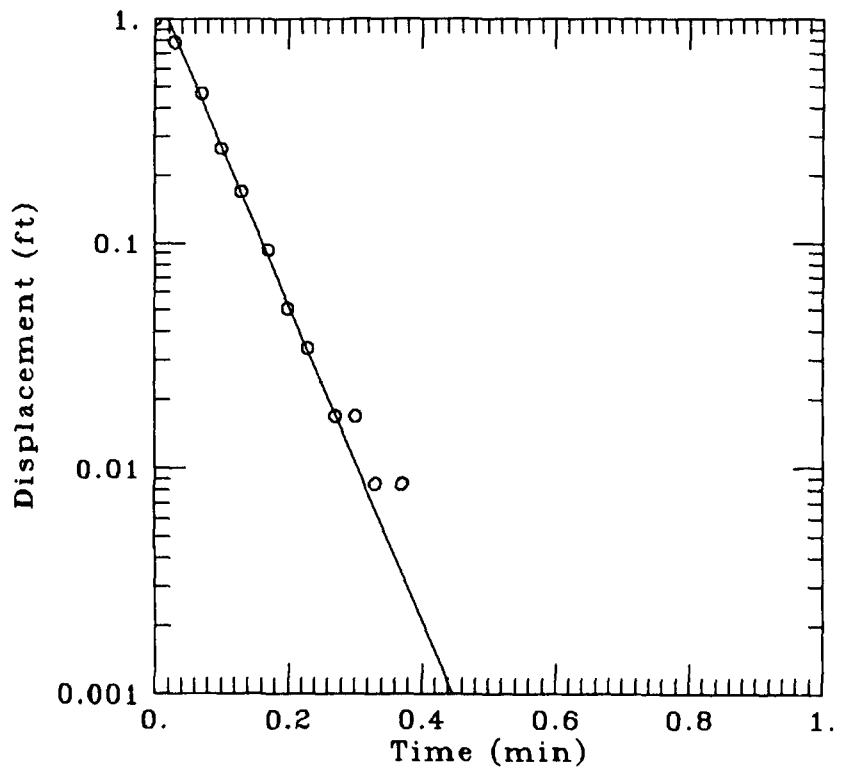
TEST DATA:

H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5.5 ft
b = 9. ft
H = 4. ft

FT-01, Well MW-1 Rising Head 2

Time	Head Change	Unit
0	1.1069	1
0.03	0.5746	1
0.07	0.3295	1
0.1	0.1943	1
0.13	0.1267	1
0.17	0.076	1
0.2	0.0507	1
0.23	0.0338	1
0.27	0.0254	1
0.3	0.0254	1
0.33	0.0169	1
0.37	0.0169	1
0.4	0.0169	1
0.43	0.0169	1
0.47	0.0169	1
0.5	0.0085	1
0.53	0.0085	1
0.57	0.0085	1
0.6	0.0085	1
0.63	0.0085	1
0.67	0.0085	1
0.7	0.0085	1
0.73	0.0085	1
0.77	0.0085	1
0.8	0.0085	1
0.83	0.0169	1
0.87	0.0085	1
0.9	0.0085	1
0.93	0.0085	1
0.97	0.0085	1
1	0.0085	1
1.03	0.0085	1
1.07	0.0085	1
1.1	0.0085	1
1.13	0.0085	1
1.17	0.0085	1
1.2	0.0085	1
1.23	0.0085	1
1.27	0.0085	1
1.3	0.0085	1
1.33	0.0085	1
1.37	0.0085	1
1.4	0.0085	1
1.43	0.0085	1
1.47	0.0085	1
1.5	0.0085	1
1.53	0.0085	1

FT-01, Well MW-3 (Falling Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.0173 ft/min
y0 = 1.35 ft

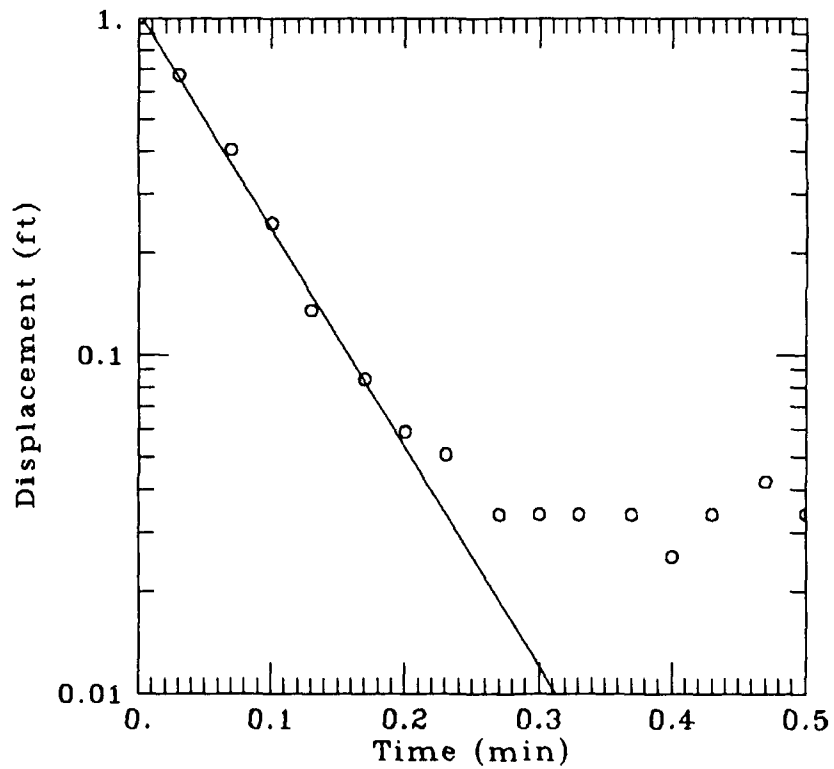
TEST DATA:

H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5.5 ft
b = 13. ft
H = 5. ft

FT-01, Well MW-3 Falling Head 1

Time	Head Change	Unit
0	1.2082	1
0.03	0.6759	1
0.07	0.4055	1
0.1	0.245	1
0.13	0.1352	1
0.17	0.0845	1
0.2	0.0591	1
0.23	0.0507	1
0.27	0.0338	1
0.3	0.0338	1
0.33	0.0338	1
0.37	0.0338	1
0.4	0.0253	1
0.43	0.0338	1
0.47	0.0422	1
0.5	0.0338	1
0.53	0.0338	1
0.57	0.0338	1
0.6	0.0338	1
0.63	0.0338	1
0.67	0.0253	1
0.7	0.0253	1
0.73	0.0253	1
0.77	0.0253	1
0.8	0.0253	1
0.83	0.0253	1
0.87	0.0338	1
0.9	0.0338	1
0.93	0.0253	1
0.97	0.0253	1
1	0.0253	1
1.03	0.0253	1
1.07	0.0253	1
1.1	0.0338	1
1.13	0.0338	1
1.17	0.0338	1
1.2	0.0338	1
1.23	0.0169	1
1.27	0.0253	1
1.3	0.0338	1
1.33	0.0253	1
1.37	0.0338	1
1.4	0.0169	1
1.43	0.0338	1
1.47	0.0338	1
1.5	0.0253	1
1.53	0.0253	1

FT-01, Well MW-3 (Falling Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

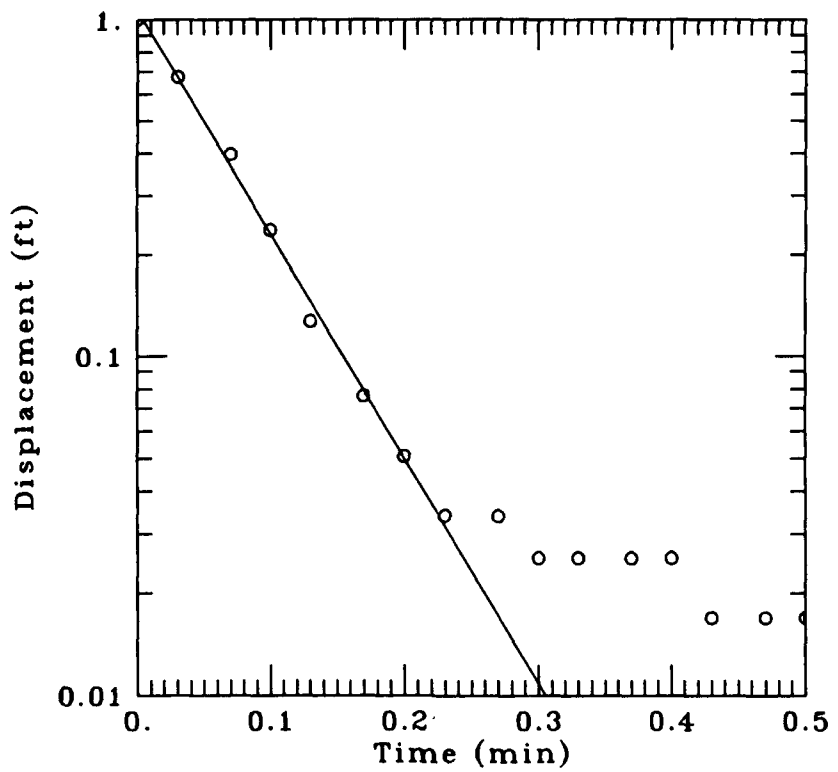
ESTIMATED PARAMETERS:
K = 0.01593 ft/min
y0 = 1.042 ft

TEST DATA:
H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5.5 ft
b = 13. ft
H = 5. ft

FT-01, Well MW-3 Falling Head 2

Time	Head Change	Unit
0	6.9192	1
0.03	0.7858	1
0.07	0.4647	1
0.1	0.2619	1
0.13	0.169	1
0.17	0.093	1
0.2	0.0507	1
0.23	0.0338	1
0.27	0.0169	1
0.3	0.0169	1
0.33	0.0085	1
0.37	0.0085	1
0.4	0	1
0.43	0	1
0.47	0	1
0.5	0	1
0.53	0	1
0.57	0	1
0.6	0	1
0.63	0	1
0.67	0	1
0.7	0	1
0.73	0	1
0.77	0	1
0.8	0	1
0.83	0	1
0.87	0	1
0.9	0	1
0.93	0	1
0.97	0	1
1	0	1

FT-01, Well MW-3 (Rising Head Test 1)



DATA SET

10/09/97

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

K = 0.01641 ft/min
y0 = 1.068 ft

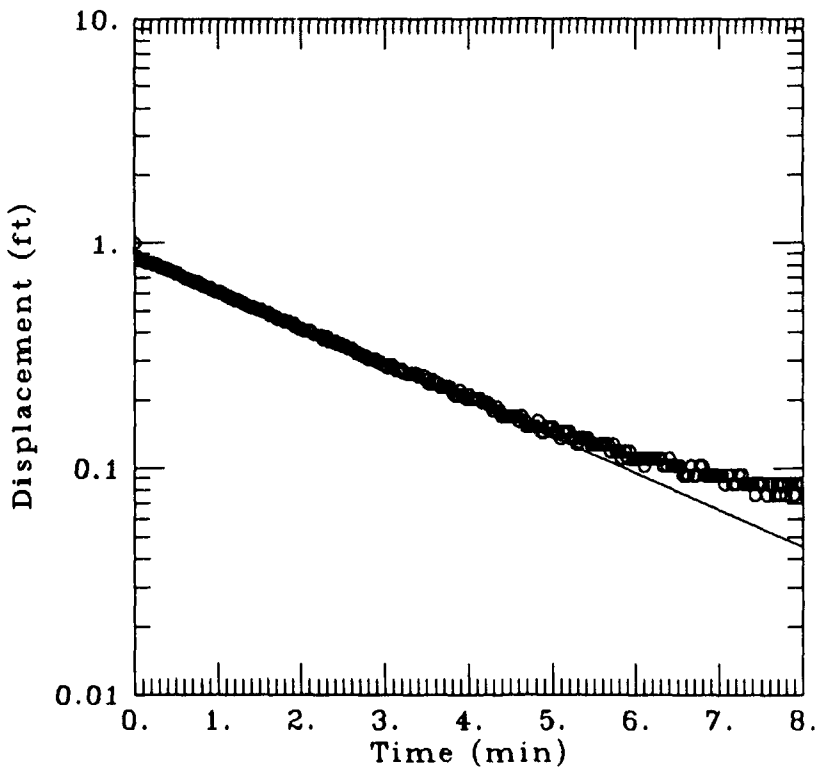
TEST DATA

H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5.5 ft
b = 13 ft
H = 5 ft

FT-01, Well MW-3 Rising Head 1

Time	Head Change	Unit
0	1.09	1
0.03	0.676	1
0.07	0.3972	1
0.1	0.2366	1
0.13	0.1268	1
0.17	0.0761	1
0.2	0.0507	1
0.23	0.0338	1
0.27	0.0338	1
0.3	0.0254	1
0.33	0.0254	1
0.37	0.0254	1
0.4	0.0254	1
0.43	0.0169	1
0.47	0.0169	1
0.5	0.0169	1
0.53	0.0169	1
0.57	0.0085	1
0.6	0.0085	1
0.63	0.0085	1
0.67	0	1
0.7	-0.0084	1
0.73	0	1
0.77	0	1
0.8	0	1
0.83	-0.0084	1
0.87	-0.0084	1
0.9	-0.0084	1
0.93	-0.0084	1
0.97	-0.0084	1
1	-0.0084	1

FT-01, Well MW-151 (Falling Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.001329 ft/min
y0 = 0.8768 ft

TEST DATA:
H0 = 1. ft
rc = 0.167 ft
rw = 0.333 ft
L = 10. ft
b = 10. ft
H = 10. ft

FT-01, Well MW-۲ Falling Head 1

Time	Head Change	Unit
0	2.913	1
0.03	2.87	1
0.07	2.854	1
0.1	2.845	1
0.13	2.828	1
0.17	2.82	1
0.2	2.82	1
0.23	2.803	1
0.27	2.803	1
0.3	2.786	1
0.33	2.778	1
0.37	2.769	1
0.4	2.761	1
0.43	2.752	1
0.47	2.744	1
0.5	2.727	1
0.53	2.727	1
0.57	2.71	1
0.6	2.701	1
0.63	2.693	1
0.67	2.685	1
0.7	2.676	1
0.73	2.668	1
0.77	2.668	1
0.8	2.651	1
0.83	2.642	1
0.87	2.634	1
0.9	2.634	1
0.93	2.617	1
0.97	2.609	1
1	2.609	1
1.03	2.6	1
1.07	2.592	1
1.1	2.583	1
1.13	2.575	1
1.17	2.566	1
1.2	2.558	1
1.23	2.558	1
1.27	2.549	1
1.3	2.541	1
1.33	2.532	1
1.37	2.524	1
1.4	2.516	1
1.43	2.516	1
1.47	2.507	1
1.5	2.507	1
1.53	2.499	1

FT-01, Well MW-1 Falling Head 1

Time	Head Change	Unit
1.57	2.49	1
1.6	2.49	1
1.63	2.473	1
1.67	2.473	1
1.7	2.465	1
1.73	2.456	1
1.77	2.456	1
1.8	2.448	1
1.83	2.448	1
1.87	2.44	1
1.9	2.44	1
1.93	2.423	1
1.97	2.414	1
2	2.414	1
2.03	2.406	1
2.07	2.406	1
2.1	2.406	1
2.13	2.397	1
2.17	2.389	1
2.2	2.389	1
2.23	2.389	1
2.27	2.372	1
2.3	2.38	1
2.33	2.364	1
2.37	2.364	1
2.4	2.364	1
2.43	2.355	1
2.47	2.355	1
2.5	2.347	1
2.53	2.347	1
2.57	2.338	1
2.6	2.338	1
2.63	2.33	1
2.67	2.321	1
2.7	2.321	1
2.73	2.313	1
2.77	2.313	1
2.8	2.304	1
2.83	2.304	1
2.87	2.304	1
2.9	2.296	1
2.93	2.296	1
2.97	2.287	1
3	2.287	1
3.03	2.279	1
3.07	2.287	1
3.1	2.279	1

FT-01, Well MW-1 Falling Head 1

Time	Head Change	Unit
3.13	2.271	1
3.17	2.271	1
3.2	2.271	1
3.23	2.262	1
3.27	2.262	1
3.3	2.262	1
3.33	2.262	1
3.37	2.262	1
3.4	2.254	1
3.43	2.245	1
3.47	2.254	1
3.5	2.245	1
3.53	2.237	1
3.57	2.245	1
3.6	2.237	1
3.63	2.237	1
3.67	2.228	1
3.7	2.228	1
3.73	2.228	1
3.77	2.228	1
3.8	2.22	1
3.83	2.211	1
3.87	2.211	1
3.9	2.22	1
3.93	2.211	1
3.97	2.203	1
4	2.211	1
4.03	2.203	1
4.07	2.203	1
4.1	2.203	1
4.13	2.203	1
4.17	2.195	1
4.2	2.195	1
4.23	2.195	1
4.27	2.186	1
4.3	2.178	1
4.33	2.186	1
4.37	2.178	1
4.4	2.169	1
4.43	2.169	1
4.47	2.169	1
4.5	2.169	1
4.53	2.169	1
4.57	2.169	1
4.6	2.161	1
4.63	2.169	1
4.67	2.161	1

FT-01, Well MW-1 Falling Head 1

Time	Head Change	Unit
4.7	2.152	1
4.73	2.152	1
4.77	2.152	1
4.8	2.152	1
4.83	2.161	1
4.87	2.144	1
4.9	2.144	1
4.93	2.152	1
4.97	2.152	1
5	2.152	1
5.03	2.144	1
5.07	2.144	1
5.1	2.135	1
5.13	2.144	1
5.17	2.144	1
5.2	2.144	1
5.23	2.135	1
5.27	2.135	1
5.3	2.127	1
5.33	2.135	1
5.37	2.135	1
5.4	2.135	1
5.43	2.135	1
5.47	2.127	1
5.5	2.127	1
5.53	2.127	1
5.57	2.127	1
5.6	2.127	1
5.63	2.127	1
5.67	2.127	1
5.7	2.118	1
5.73	2.127	1
5.77	2.118	1
5.8	2.118	1
5.83	2.11	1
5.87	2.118	1
5.9	2.11	1
5.93	2.118	1
5.97	2.11	1
6	2.11	1
6.03	2.11	1
6.07	2.11	1
6.1	2.102	1
6.13	2.11	1
6.17	2.11	1
6.2	2.11	1
6.23	2.11	1

FT-01, Well MW-1 Falling Head 1

Time	Head Change	Unit
6.27	2.11	1
6.3	2.11	1
6.33	2.102	1
6.37	2.102	1
6.4	2.11	1
6.43	2.102	1
6.47	2.102	1
6.5	2.102	1
6.53	2.102	1
6.57	2.093	1
6.6	2.093	1
6.63	2.093	1
6.67	2.102	1
6.7	2.093	1
6.73	2.093	1
6.77	2.102	1
6.8	2.102	1
6.83	2.093	1
6.87	2.093	1
6.9	2.093	1
6.93	2.093	1
6.97	2.093	1
7	2.093	1
7.03	2.093	1
7.07	2.085	1
7.1	2.093	1
7.13	2.093	1
7.17	2.085	1
7.2	2.085	1
7.23	2.093	1
7.27	2.093	1
7.3	2.085	1
7.33	2.085	1
7.37	2.085	1
7.4	2.085	1
7.43	2.076	1
7.47	2.085	1
7.5	2.085	1
7.53	2.085	1
7.57	2.076	1
7.6	2.085	1
7.63	2.085	1
7.67	2.076	1
7.7	2.085	1
7.73	2.076	1
7.77	2.085	1
7.8	2.076	1

FT-01, Well MW-1 Falling Head 1

Time	Head Change	Unit
7.83	2.085	1
7.87	2.085	1
7.9	2.076	1
7.93	2.085	1
7.97	2.085	1
8	2.085	1
8.03	2.076	1
8.07	2.068	1
8.1	2.076	1
8.13	2.076	1
8.17	2.068	1
8.2	2.076	1
8.23	2.076	1
8.27	2.068	1
8.3	2.068	1
8.33	2.068	1
8.37	2.068	1
8.4	2.076	1
8.43	2.076	1
8.47	2.076	1
8.5	2.076	1
8.53	2.076	1
8.57	2.076	1
8.6	2.068	1
8.63	2.068	1
8.67	2.076	1
8.7	2.076	1
8.73	2.068	1
8.77	2.068	1
8.8	2.068	1
8.83	2.068	1
8.87	2.068	1
8.9	2.068	1
8.93	2.068	1
8.97	2.068	1
9	2.068	1
9.03	2.068	1
9.07	2.068	1
9.1	2.068	1
9.13	2.068	1
9.17	2.068	1
9.2	2.068	1
9.23	2.068	1
9.27	2.068	1
9.3	2.068	1
9.33	2.068	1
9.37	2.059	1

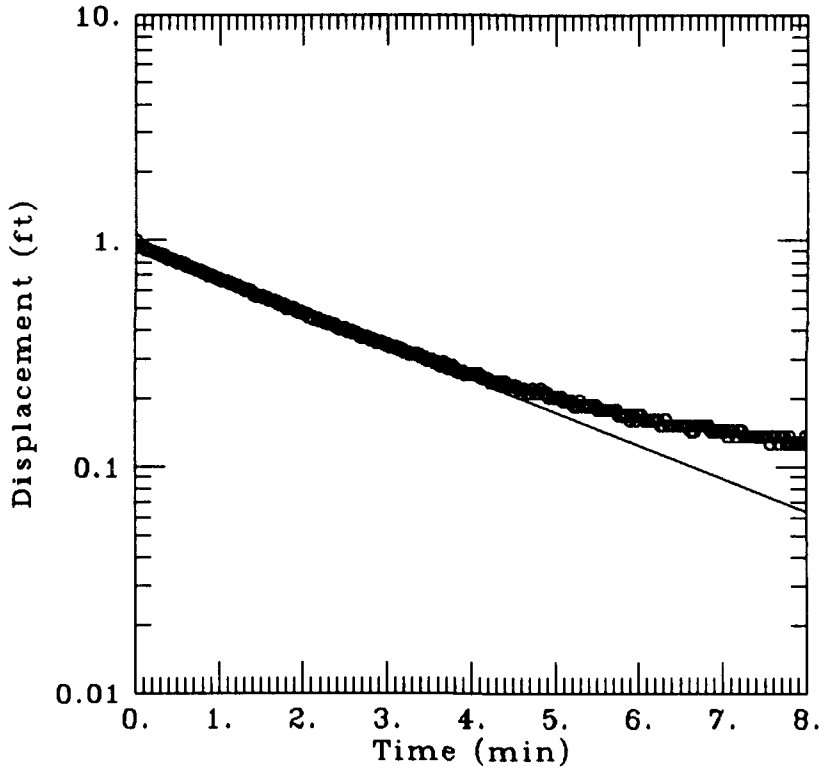
FT-01, Well MW-1 Falling Head 1

Time	Head Change	Unit
9.4	2.068	1
9.43	2.068	1
9.47	2.059	1
9.5	2.068	1
9.53	2.059	1
9.57	2.068	1
9.6	2.068	1
9.63	2.068	1
9.67	2.068	1
9.7	2.068	1
9.73	2.068	1
9.77	2.068	1
9.8	2.059	1
9.83	2.068	1
9.87	2.059	1
9.9	2.068	1
9.93	2.059	1
9.97	2.068	1
10	2.059	1
10.03	2.068	1
10.07	2.059	1
10.1	2.059	1
10.13	2.068	1
10.17	2.068	1
10.2	2.059	1
10.23	2.059	1
10.27	2.059	1
10.3	2.059	1
10.33	2.068	1
10.37	2.059	1
10.4	2.059	1
10.43	2.059	1
10.47	2.059	1
10.5	2.068	1
10.53	2.059	1
10.57	2.059	1
10.6	2.068	1
10.63	2.059	1
10.67	2.068	1
10.7	2.068	1
10.73	2.068	1
10.77	2.059	1
10.8	2.059	1
10.83	2.068	1
10.87	2.068	1
10.9	2.059	1
10.93	2.059	1

FT-01, Well MW-1 Falling Head 1

Time	Head Change	Unit
10.97	2.059	1
11	2.059	1
11.0[illegible]	2.059	1
11.[illegible]	2.059	1
11[illegible]	2.068	1
11.13	2.059	1
11.17	2.059	1
11.2	2.068	1
11.23	2.059	1
11.27	2.059	1
11.3	2.059	1
11.33	2.068	1
11.37	2.068	1
11.4	2.068	1
11.43	2.059	1
11.47	2.059	1
11.5	2.059	1
11.53	2.059	1
11.57	2.051	1
11.6	2.059	
11.63	2.059	
11.67	2.059	
11.7	2.059	1
11.73	2.059	1
11.77	2.059	1
11.8	2.059	1
11.83	2.059	1
11.87	2.059	1
11.9	2.059	1
11.93	2.059	1
11.97	2.059	1
12	2.059	1
12.03	2.059	1
12.07	2.059	1
12.1	2.059	1
12.13	2.059	1
12.17	2.059	1
12.2	2.059	1
12.23	2.059	1
12.27	2.059	1
12.3	2.051	1
12.33	2.059	1
12.37	2.059	1
12.4	2.059	1
12.43	2.059	1

FT-01, Well MW-151 (Falling Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.001206 ft/min
y0 = 0.9383 ft

TEST DATA:

H0 = 1. ft
rc = 0.167 ft
rw = 0.333 ft
L = 10. ft
b = 10. ft
H = 10. ft

FT-01, Well MW-151 Falling Head 2

Time	Head Change	Unit
0	1.006	1
0.03	0.938	1
0.07	0.93	1
0.1	0.921	1
0.13	0.904	1
0.17	0.896	1
0.2	0.888	1
0.23	0.879	1
0.27	0.871	1
0.3	0.854	1
0.33	0.854	1
0.37	0.828	1
0.4	0.828	1
0.43	0.82	1
0.47	0.803	1
0.5	0.795	1
0.53	0.795	1
0.57	0.786	1
0.6	0.769	1
0.63	0.761	1
0.67	0.752	1
0.7	0.744	1
0.73	0.735	1
0.77	0.727	1
0.8	0.719	1
0.83	0.71	1
0.87	0.693	1
0.9	0.693	1
0.93	0.685	1
0.97	0.676	1
1	0.668	1
1.03	0.659	1
1.07	0.659	1
1.1	0.651	1
1.13	0.642	1
1.17	0.634	1
1.2	0.626	1
1.23	0.617	1
1.27	0.609	1
1.3	0.6	1
1.33	0.6	1
1.37	0.592	1
1.4	0.575	1
1.43	0.566	1
1.47	0.566	1
1.5	0.566	1
1.53	0.558	1

FT-01, Well MW-151 Falling Head 2

Time	Head Change	Unit
1.57	0.55	1
1.6	0.541	1
1.63	0.541	1
1.67	0.533	1
1.7	0.524	1
1.73	0.516	1
1.77	0.516	1
1.8	0.499	1
1.83	0.499	1
1.87	0.499	1
1.9	0.49	1
1.93	0.482	1
1.97	0.482	1
2	0.473	1
2.03	0.473	1
2.07	0.457	1
2.1	0.457	1
2.13	0.448	1
2.17	0.448	1
2.2	0.44	1
2.23	0.44	1
2.27	0.431	1
2.3	0.431	1
2.33	0.423	1
2.37	0.423	1
2.4	0.414	1
2.43	0.406	1
2.47	0.406	1
2.5	0.406	1
2.53	0.397	1
2.57	0.397	1
2.6	0.389	1
2.63	0.389	1
2.67	0.381	1
2.7	0.372	1
2.73	0.372	1
2.77	0.372	1
2.8	0.364	1
2.83	0.364	1
2.87	0.355	1
2.9	0.355	1
2.93	0.355	1
2.97	0.347	1
3	0.347	1
3.03	0.338	1
3.07	0.338	1
3.1	0.338	1

FT-01, Well MW-151 Falling Head 2

Time	Head Change	Unit
3.13	0.33	1
3.17	0.33	1
3.2	0.321	1
3.23	0.321	1
3.27	0.313	1
3.3	0.313	1
3.33	0.313	1
3.37	0.313	1
3.4	0.305	1
3.43	0.305	1
3.47	0.296	1
3.5	0.296	1
3.53	0.296	1
3.57	0.288	1
3.6	0.288	1
3.63	0.279	1
3.67	0.288	1
3.7	0.279	1
3.73	0.271	1
3.77	0.279	1
3.8	0.271	1
3.83	0.262	1
3.87	0.262	1
3.9	0.262	1
3.93	0.254	1
3.97	0.254	1
4	0.254	1
4.03	0.254	1
4.07	0.254	1
4.1	0.254	1
4.13	0.245	1
4.17	0.245	1
4.2	0.245	1
4.23	0.237	1
4.27	0.237	1
4.3	0.237	1
4.33	0.237	1
4.37	0.237	1
4.4	0.237	1
4.43	0.228	1
4.47	0.228	1
4.5	0.228	1
4.53	0.228	1
4.57	0.22	1
4.6	0.22	1
4.63	0.22	1
4.67	0.212	1

FT-01, Well MW-151 Falling Head 2

Time	Head Change	Unit
4.7	0.212	1
4.73	0.22	1
4.77	0.212	1
4.8	0.212	1
4.83	0.22	1
4.87	0.212	1
4.9	0.212	1
4.93	0.203	1
4.97	0.203	1
5	0.203	1
5.03	0.203	1
5.07	0.203	1
5.1	0.195	1
5.13	0.195	1
5.17	0.195	1
5.2	0.195	1
5.23	0.186	1
5.27	0.186	1
5.3	0.195	1
5.33	0.186	1
5.37	0.186	1
5.4	0.186	1
5.43	0.186	1
5.47	0.186	1
5.5	0.186	1
5.53	0.178	1
5.57	0.178	1
5.6	0.178	1
5.63	0.178	1
5.67	0.178	1
5.7	0.178	1
5.73	0.178	1
5.77	0.169	1
5.8	0.169	1
5.83	0.169	1
5.87	0.169	1
5.9	0.161	1
5.93	0.169	1
5.97	0.161	1
6	0.169	1
6.03	0.169	1
6.07	0.161	1
6.1	0.161	1
6.13	0.161	1
6.17	0.161	1
6.2	0.161	1
6.23	0.161	1

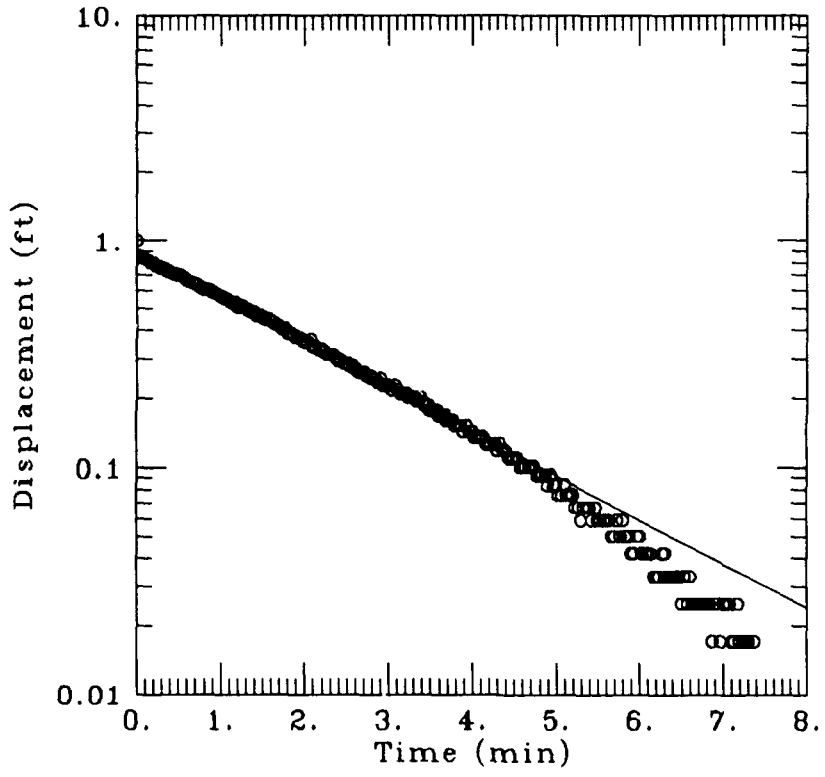
FT-01, Well MW-151 Falling Head 2

Time	Head Change	Unit
6.27	0.152	1
6.3	0.152	1
6.33	0.161	1
6.37	0.152	1
6.4	0.152	1
6.43	0.152	1
6.47	0.152	1
6.5	0.152	1
6.53	0.152	1
6.57	0.152	1
6.6	0.152	1
6.63	0.144	1
6.67	0.144	1
6.7	0.152	1
6.73	0.152	1
6.77	0.152	1
6.8	0.152	1
6.83	0.152	1
6.87	0.144	1
6.9	0.144	1
6.93	0.144	1
6.97	0.144	1
7	0.144	1
7.03	0.144	1
7.07	0.136	1
7.1	0.144	1
7.13	0.144	1
7.17	0.136	1
7.2	0.144	1
7.23	0.144	1
7.27	0.136	1
7.3	0.136	1
7.33	0.136	1
7.37	0.136	1
7.4	0.136	1
7.43	0.136	1
7.47	0.136	1
7.5	0.136	1
7.53	0.136	1
7.57	0.127	1
7.6	0.136	1
7.63	0.136	1
7.67	0.127	1
7.7	0.136	1
7.73	0.136	1
7.77	0.127	1
7.8	0.136	1

FT-01, Well MW-151 Falling Head 2

Time	Head Change	Unit
7.83	0.127	1
7.87	0.127	1
7.9	0.127	1
7.93	0.127	1
7.97	0.127	1
8	0.136	1
8.03	0.127	1
8.07	0.127	1

FT-01, Well MW-151 (Rising Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.001615 ft/min
y0 = 0.8804 ft

TEST DATA:

H0 = 1. ft
rc = 0.167 ft
rw = 0.333 ft
L = 10. ft
b = 10. ft
H = 10. ft

FT-01, Well MW-151 Rising Head 1

Time	Head Change	Unit
0	0.98	1
0.03	0.853	1
0.07	0.845	1
0.1	0.828	1
0.13	0.819	1
0.17	0.802	1
0.2	0.794	1
0.23	0.777	1
0.27	0.769	1
0.3	0.752	1
0.33	0.752	1
0.37	0.735	1
0.4	0.726	1
0.43	0.718	1
0.47	0.709	1
0.5	0.701	1
0.53	0.701	1
0.57	0.684	1
0.6	0.667	1
0.63	0.659	1
0.67	0.65	1
0.7	0.642	1
0.73	0.633	1
0.77	0.616	1
0.8	0.608	1
0.83	0.608	1
0.87	0.6	1
0.9	0.591	1
0.93	0.583	1
0.97	0.574	1
1	0.566	1
1.03	0.557	1
1.07	0.549	1
1.1	0.54	1
1.13	0.532	1
1.17	0.532	1
1.2	0.507	1
1.23	0.515	1
1.27	0.507	1
1.3	0.498	1
1.33	0.49	1
1.37	0.481	1
1.4	0.481	1
1.43	0.464	1
1.47	0.464	1
1.5	0.456	1
1.53	0.447	1

FT-01, Well MW-151 Rising Head 1

Time	Head Change	Unit
1.57	0.447	1
1.6	0.439	1
1.63	0.431	1
1.67	0.422	1
1.7	0.414	1
1.73	0.405	1
1.77	0.405	1
1.8	0.388	1
1.83	0.388	1
1.87	0.38	1
1.9	0.371	1
1.93	0.371	1
1.97	0.363	1
2	0.355	1
2.03	0.355	1
2.07	0.363	1
2.1	0.338	1
2.13	0.338	1
2.17	0.329	1
2.2	0.329	1
2.23	0.321	1
2.27	0.312	1
2.3	0.312	1
2.33	0.312	1
2.37	0.304	1
2.4	0.295	1
2.43	0.295	1
2.47	0.287	1
2.5	0.287	1
2.53	0.279	1
2.57	0.279	1
2.6	0.27	1
2.63	0.262	1
2.67	0.262	1
2.7	0.262	1
2.73	0.253	1
2.77	0.253	1
2.8	0.245	1
2.83	0.245	1
2.87	0.236	1
2.9	0.245	1
2.93	0.228	1
2.97	0.228	1
3	0.228	1
3.03	0.219	1
3.07	0.228	1
3.1	0.219	1

FT-01, Well MW-151 Rising Head 1

Time	Head Change	Unit
3.13	0.211	1
3.17	0.211	1
3.2	0.211	1
3.23	0.202	1
3.27	0.202	1
3.3	0.202	1
3.33	0.194	1
3.37	0.202	1
3.4	0.194	1
3.43	0.186	1
3.47	0.186	1
3.5	0.177	1
3.53	0.177	1
3.57	0.177	1
3.6	0.169	1
3.63	0.169	1
3.67	0.169	1
3.7	0.16	1
3.73	0.16	1
3.77	0.16	1
3.8	0.152	1
3.83	0.152	1
3.87	0.152	1
3.9	0.143	1
3.93	0.152	1
3.97	0.143	1
4	0.143	1
4.03	0.135	1
4.07	0.135	1
4.1	0.135	1
4.13	0.135	1
4.17	0.126	1
4.2	0.126	1
4.23	0.126	1
4.27	0.126	1
4.3	0.118	1
4.33	0.126	1
4.37	0.118	1
4.4	0.118	1
4.43	0.11	1
4.47	0.11	1
4.5	0.11	1
4.53	0.11	1
4.57	0.101	1
4.6	0.101	1
4.63	0.101	1
4.67	0.101	1

FT-01, Well MW-151 Rising Head 1

Time	Head Change	Unit
4.7	0.101	1
4.73	0.101	1
4.77	0.093	1
4.8	0.093	1
4.83	0.093	1
4.87	0.093	1
4.9	0.084	1
4.93	0.093	1
4.97	0.084	1
5	0.084	1
5.03	0.076	1
5.07	0.076	1
5.1	0.084	1
5.13	0.076	1
5.17	0.076	1
5.2	0.076	1
5.23	0.067	1
5.27	0.067	1
5.3	0.059	1
5.33	0.067	1
5.37	0.067	1
5.4	0.067	1
5.43	0.059	1
5.47	0.067	1
5.5	0.059	1
5.53	0.059	1
5.57	0.059	1
5.6	0.059	1
5.63	0.059	1
5.67	0.05	1
5.7	0.05	1
5.73	0.059	1
5.77	0.05	1
5.8	0.059	1
5.83	0.05	1
5.87	0.05	1
5.9	0.042	1
5.93	0.042	1
5.97	0.05	1
6	0.05	1
6.03	0.042	1
6.07	0.042	1
6.1	0.042	1
6.13	0.042	1
6.17	0.033	1
6.2	0.033	1
6.23	0.033	1

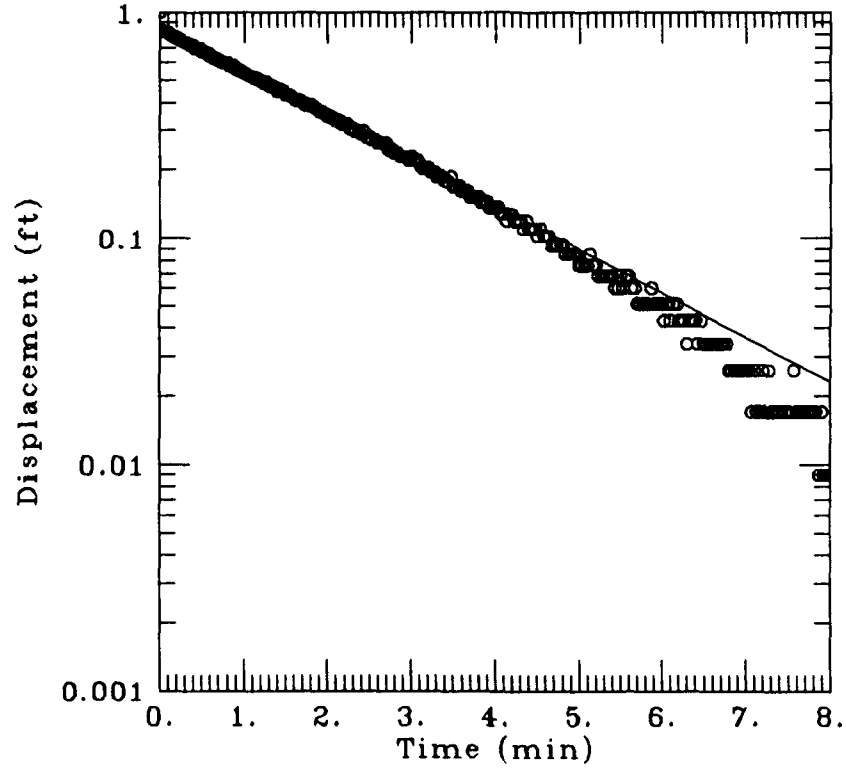
FT-01, Well MW-151 Rising Head 1

Time	Head Change	Unit
6.27	0.042	1
6.3	0.042	1
6.33	0.033	1
6.37	0.033	1
6.4	0.033	1
6.43	0.033	1
6.47	0.033	1
6.5	0.025	1
6.53	0.033	1
6.57	0.025	1
6.6	0.033	1
6.63	0.025	1
6.67	0.025	1
6.7	0.025	1
6.73	0.025	1
6.77	0.025	1
6.8	0.025	1
6.83	0.025	1
6.87	0.017	1
6.9	0.025	1
6.93	0.025	1
6.97	0.017	1
7	0.025	1
7.03	0.025	1
7.07	0.025	1
7.1	0.017	1
7.13	0.017	1
7.17	0.025	1
7.2	0.017	1
7.23	0.017	1
7.27	0.017	1
7.3	0.017	1
7.33	0.008	1
7.37	0.017	1
7.4	0.008	1
7.43	0.008	1
7.47	0.008	1
7.5	0.008	1
7.53	0.008	1
7.57	0.008	1
7.6	0.008	1
7.63	0.008	1
7.67	0.008	1
7.7	0.008	1
7.73	0.008	1
7.77	0.008	1
7.8	0.008	1

FT-01, Well MW-151 Rising Head 1

Time	Head Change	Unit
7.83	0.008	1
7.87	0.008	1
7.9	0.008	1
7.93	0.008	1
7.97	0.008	1
8	0	1
8.03	0	1
8.07	0	1
8.1	0	1
8.13	0	1

FT-01, Well MW-151 (Rising Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.001613 ft/min
y0 = 0.8514 ft

TEST DATA:

H0 = 1. ft
rc = 0.167 ft
rw = 0.333 ft
L = 10. ft
b = 10. ft
H = 10. ft

FT-01, Well MW-151 Rising Head 2

Time	Head Change	Unit
0	0.854	1
0.03	0.828	1
0.07	0.82	1
0.1	0.812	1
0.13	0.795	1
0.17	0.778	1
0.2	0.769	1
0.23	0.761	1
0.27	0.744	1
0.3	0.735	1
0.33	0.727	1
0.37	0.719	1
0.4	0.71	1
0.43	0.693	1
0.47	0.693	1
0.5	0.676	1
0.53	0.668	1
0.57	0.659	1
0.6	0.643	1
0.63	0.634	1
0.67	0.626	1
0.7	0.617	1
0.73	0.609	1
0.77	0.6	1
0.8	0.6	1
0.83	0.583	1
0.87	0.583	1
0.9	0.566	1
0.93	0.558	1
0.97	0.55	1
1	0.541	1
1.03	0.533	1
1.07	0.524	1
1.1	0.516	1
1.13	0.516	1
1.17	0.507	1
1.2	0.499	1
1.23	0.49	1
1.27	0.49	1
1.3	0.474	1
1.33	0.474	1
1.37	0.465	1
1.4	0.448	1
1.43	0.457	1
1.47	0.448	1
1.5	0.431	1
1.53	0.431	1

FT-01, Well MW-151 Rising Head 2

Time	Head Change	Unit
1.57	0.423	1
1.6	0.414	1
1.63	0.406	1
1.67	0.406	1
1.7	0.398	1
1.73	0.389	1
1.77	0.389	1
1.8	0.389	1
1.83	0.381	1
1.87	0.372	1
1.9	0.364	1
1.93	0.364	1
1.97	0.355	1
2	0.347	1
2.03	0.347	1
2.07	0.338	1
2.1	0.33	1
2.13	0.33	1
2.17	0.321	1
2.2	0.321	1
2.23	0.321	1
2.27	0.305	1
2.3	0.305	1
2.33	0.296	1
2.37	0.296	1
2.4	0.288	1
2.43	0.296	1
2.47	0.279	1
2.5	0.279	1
2.53	0.271	1
2.57	0.271	1
2.6	0.262	1
2.63	0.262	1
2.67	0.262	1
2.7	0.262	1
2.73	0.245	1
2.77	0.245	1
2.8	0.237	1
2.83	0.237	1
2.87	0.229	1
2.9	0.229	1
2.93	0.229	1
2.97	0.22	1
3	0.229	1
3.03	0.22	1
3.07	0.22	1
3.1	0.212	1

FT-01, Well MW-151 Rising Head 2

Time	Head Change	Unit
3.13	0.203	1
3.17	0.203	1
3.2	0.203	1
3.23	0.195	1
3.27	0.195	1
3.3	0.186	1
3.33	0.186	1
3.37	0.186	1
3.4	0.178	1
3.43	0.178	1
3.47	0.186	1
3.5	0.169	1
3.53	0.169	1
3.57	0.169	1
3.6	0.161	1
3.63	0.161	1
3.67	0.161	1
3.7	0.152	1
3.73	0.152	1
3.77	0.152	1
3.8	0.152	1
3.83	0.144	1
3.87	0.144	1
3.9	0.144	1
3.93	0.136	1
3.97	0.136	1
4	0.136	1
4.03	0.136	1
4.07	0.127	1
4.1	0.127	1
4.13	0.119	1
4.17	0.127	1
4.2	0.127	1
4.23	0.119	1
4.27	0.119	1
4.3	0.119	1
4.33	0.11	1
4.37	0.119	1
4.4	0.11	1
4.43	0.11	1
4.47	0.11	1
4.5	0.102	1
4.53	0.11	1
4.57	0.102	1
4.6	0.102	1
4.63	0.102	1
4.67	0.093	1

FT-01, Well MW-151 Rising Head 2

Time	Head Change	Unit
4.7	0.093	1
4.73	0.093	1
4.77	0.093	1
4.8	0.093	1
4.83	0.085	1
4.87	0.085	1
4.9	0.085	1
4.93	0.085	1
4.97	0.085	1
5	0.076	1
5.03	0.076	1
5.07	0.076	1
5.1	0.076	1
5.13	0.085	1
5.17	0.076	1
5.2	0.076	1
5.23	0.068	1
5.27	0.068	1
5.3	0.068	1
5.33	0.068	1
5.37	0.068	1
5.4	0.068	1
5.43	0.06	1
5.47	0.06	1
5.5	0.068	1
5.53	0.06	1
5.57	0.068	1
5.6	0.068	1
5.63	0.06	1
5.67	0.06	1
5.7	0.051	1
5.73	0.051	1
5.77	0.051	1
5.8	0.051	1
5.83	0.051	1
5.87	0.06	1
5.9	0.051	1
5.93	0.051	1
5.97	0.051	1
6	0.051	1
6.03	0.043	1
6.07	0.051	1
6.1	0.043	1
6.13	0.051	1
6.17	0.051	1
6.2	0.043	1
6.23	0.043	1

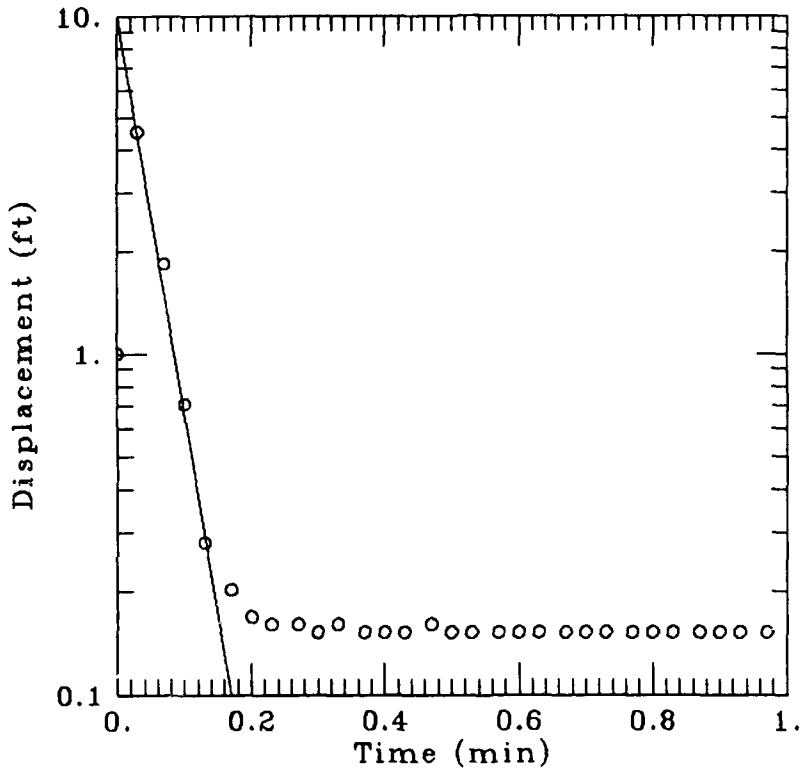
FT-01, Well MW-151 Rising Head 2

Time	Head Change	Unit
6.27	0.043	1
6.3	0.034	1
6.33	0.043	1
6.37	0.043	1
6.4	0.043	1
6.43	0.034	1
6.47	0.043	1
6.5	0.034	1
6.53	0.034	1
6.57	0.034	1
6.6	0.034	1
6.63	0.034	1
6.67	0.034	1
6.7	0.034	1
6.73	0.034	1
6.77	0.034	1
6.8	0.026	1
6.83	0.026	1
6.87	0.026	1
6.9	0.026	1
6.93	0.026	1
6.97	0.026	1
7	0.026	1
7.03	0.026	1
7.07	0.017	1
7.1	0.026	1
7.13	0.017	1
7.17	0.017	1
7.2	0.026	1
7.23	0.017	1
7.27	0.026	1
7.3	0.017	1
7.33	0.017	1
7.37	0.017	1
7.4	0.017	1
7.43	0.017	1
7.47	0.017	1
7.5	0.017	1
7.53	0.017	1
7.57	0.026	1
7.6	0.017	1
7.63	0.017	1
7.67	0.017	1
7.7	0.017	1
7.73	0.017	1
7.77	0.017	1
7.8	0.017	1

FT-01, Well MW-151 Rising Head 2

Time	Head Change	Unit
7.83	0.017	1
7.87	0.009	1
7.9	0.017	1
7.93	0.009	1
7.97	0.009	1
8	0.009	1
8.03	0.009	1
8.07	0.009	1
8.1	0.017	1
8.13	0.009	1
8.17	0.009	1
8.2	0.009	1
8.23	0.009	1
8.27	0.009	1
8.3	0.009	1
8.33	0.009	1
8.37	0.009	1
8.4	0.009	1
8.43	0.009	1
8.47	0.009	1
8.5	0.009	1
8.53	0.009	1
8.57	0.009	1
8.6	0.009	1
8.63	0.009	1
8.67	0.009	1
8.7	0.009	1
8.73	0	1
8.77	0	1
8.8	0.009	1
8.83	0.009	1
8.87	0	1
8.9	0	1
8.93	0.009	1
8.97	0	1
9	0	1
9.03	0	1
9.07	0	1
9.1	0	1
9.13	0	1
9.17	0	1
9.2	0	1

FT-01, Well MW-153 (Falling Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

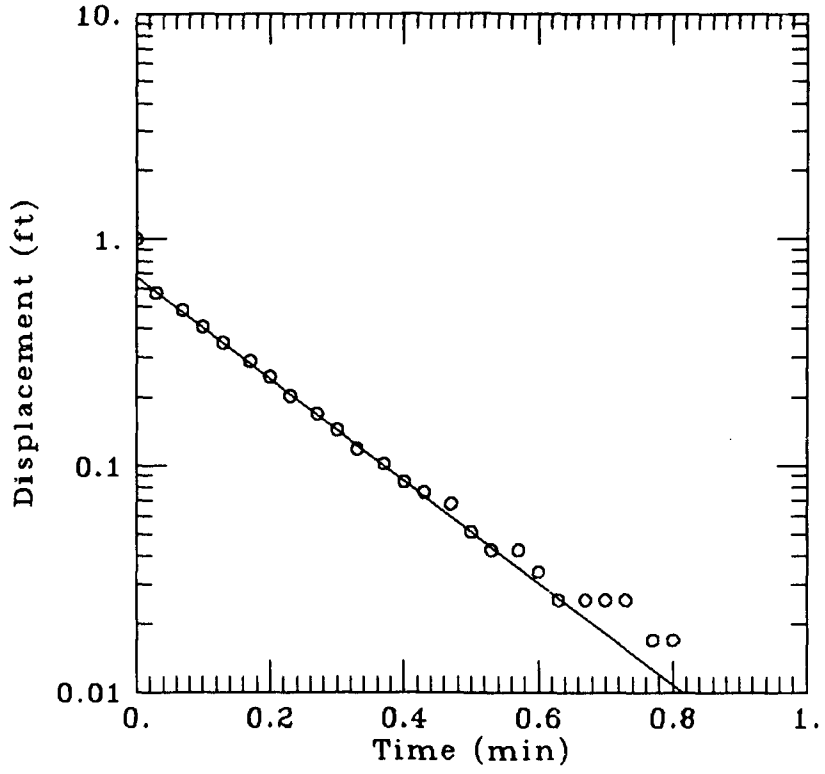
ESTIMATED PARAMETERS:
K = 0.02944 ft/min
y0 = 10. ft

TEST DATA:
H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5. ft
b = 13. ft
H = 4. ft

FT-01, Well MW-153 Falling Head 1

Time	Head Change	Unit
0	4.5288	1
0.03	4.5288	1
0.07	1.8419	1
0.1	0.7097	1
0.13	0.2788	1
0.17	0.2028	1
0.2	0.169	1
0.23	0.1605	1
0.27	0.1605	1
0.3	0.1521	1
0.33	0.1605	1
0.37	0.1521	1
0.4	0.1521	1
0.43	0.1521	1
0.47	0.1605	1
0.5	0.1521	1
0.53	0.1521	1
0.57	0.1521	1
0.6	0.1521	1
0.63	0.1521	1
0.67	0.1521	1
0.7	0.1521	1
0.73	0.1521	1
0.77	0.1521	1
0.8	0.1521	1
0.83	0.1521	1
0.87	0.1521	1
0.9	0.1521	1
0.93	0.1521	1
0.97	0.1521	1

FT-01, Well MW-153 (Falling Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.005611 ft/min
y0 = 0.6816 ft

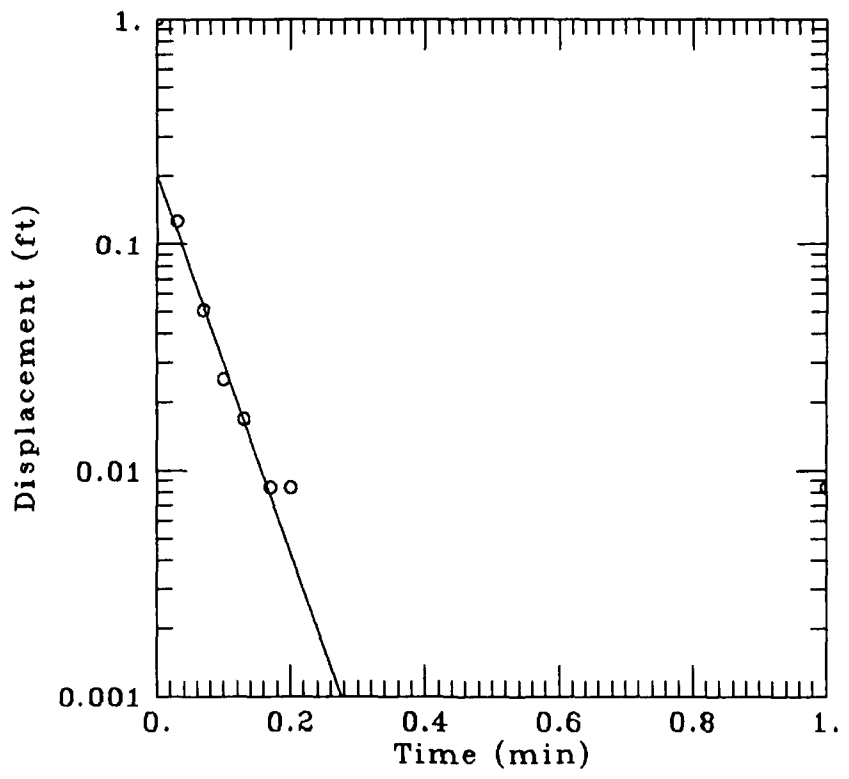
TEST DATA:

H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5. ft
b = 13. ft
H = 4. ft

FT-01, Well MW-153 Falling Head 2

Time	Head Change	Unit
0	0.6929	1
0.03	0.5746	1
0.07	0.4816	1
0.1	0.4056	1
0.13	0.3464	1
0.17	0.2873	1
0.2	0.245	1
0.23	0.2028	1
0.27	0.169	1
0.3	0.1437	1
0.33	0.1183	1
0.37	0.1014	1
0.4	0.0845	1
0.43	0.0761	1
0.47	0.0676	1
0.5	0.0507	1
0.53	0.0423	1
0.57	0.0423	1
0.6	0.0338	1
0.63	0.0254	1
0.67	0.0254	1
0.7	0.0254	1
0.73	0.0254	1
0.77	0.0169	1
0.8	0.0169	1
0.83	0.0085	1
0.87	0.0085	1
0.9	0.0085	1
0.93	0	1
0.97	0.0085	1
1	0	1
1.03	0	1
1.07	0	1
1.1	0	1
1.13	0	1
1.17	-0.0084	1

FT-01, Well MW-153 (Rising Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

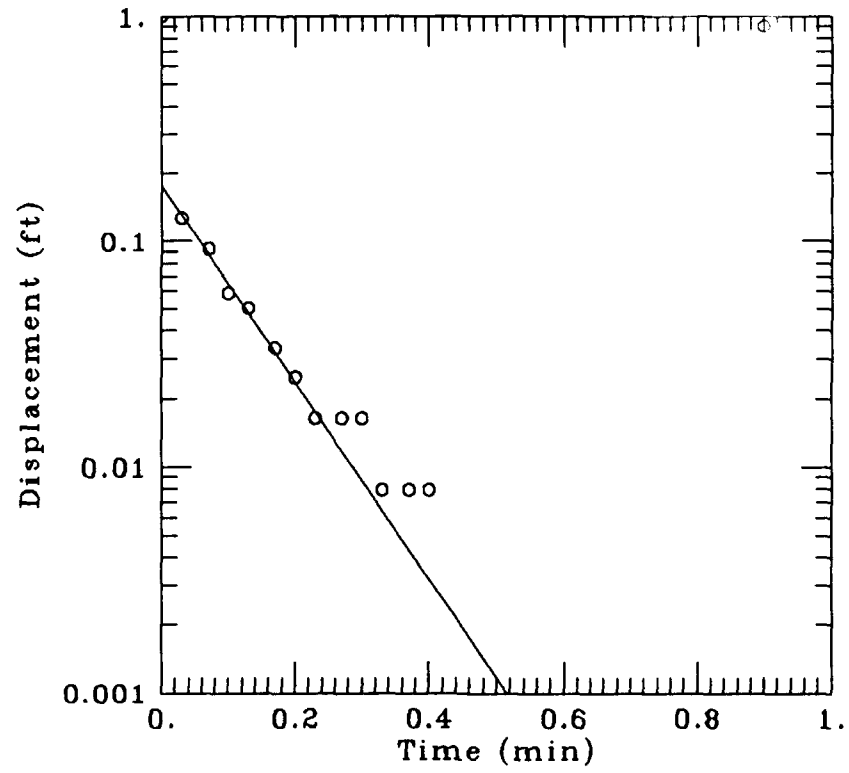
ESTIMATED PARAMETERS:
K = 0.02083 ft/min
y0 = 0.2028 ft

TEST DATA:
H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5. ft
b = 13. ft
H = 4. ft

FT-01, Well MW-153 Rising Head 1

Time	Head Change	Unit
0	0.1605	1
0.03	0.1267	1
0.07	0.0507	1
0.1	0.0253	1
0.13	0.0169	1
0.17	0.0084	1
0.2	0.0084	1
0.23	0	1
0.27	0	1
0.3	0	1
0.33	0	1
0.37	0	1
0.4	0	1
0.43	0	1
0.47	0	1
0.5	0	1
0.53	0	1
0.57	0	1
0.6	0	1
0.63	0	1
0.67	0	1
0.7	0	1
0.73	0	1
0.77	0	1
0.8	0	1
0.83	0	1
0.87	0	1
0.9	0	1
0.93	0	1
0.97	0	1
1	0.0084	1
1.03	0	1

FT-01, Well MW-153 (Rising Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.01084 ft/min
y0 = 0.1753 ft

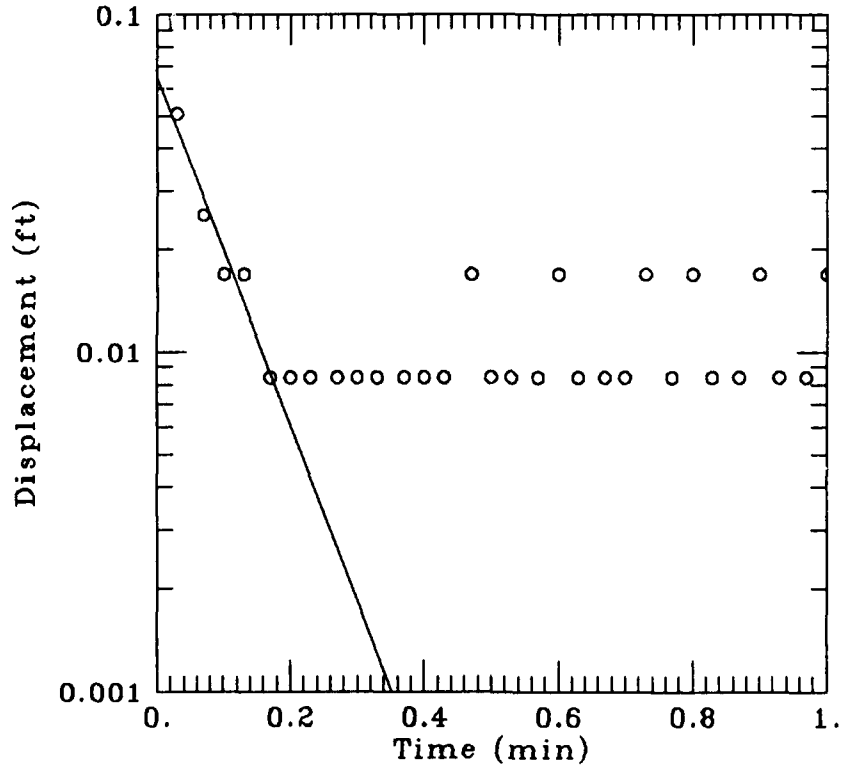
TEST DATA:

H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5. ft
b = 13. ft
H = 4. ft

FT-01, Well MW-153 Rising Head 2

Time	Head Change	Unit
0	0.2614	1
0.03	0.1262	1
0.07	0.0924	1
0.1	0.0586	1
0.13	0.0502	1
0.17	0.0333	1
0.2	0.0248	1
0.23	0.0164	1
0.27	0.0164	1
0.3	0.0164	1
0.33	0.0079	1
0.37	0.0079	1
0.4	0.0079	1
0.43	-0.0005	1
0.47	-0.0005	1
0.5	-0.0005	1
0.53	-0.0005	1
0.57	-0.0005	1
0.6	-0.0005	1
0.63	-0.0005	1
0.67	-0.0005	1
0.7	-0.0005	1
0.73	-0.0005	1
0.77	-0.0005	1
0.8	-0.0005	1
0.83	-0.009	1
0.87	-0.009	1
0.9	0.9	1

FT-01, Well MW-155 (Falling Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.0133 ft/min
y0 = 0.06518 ft

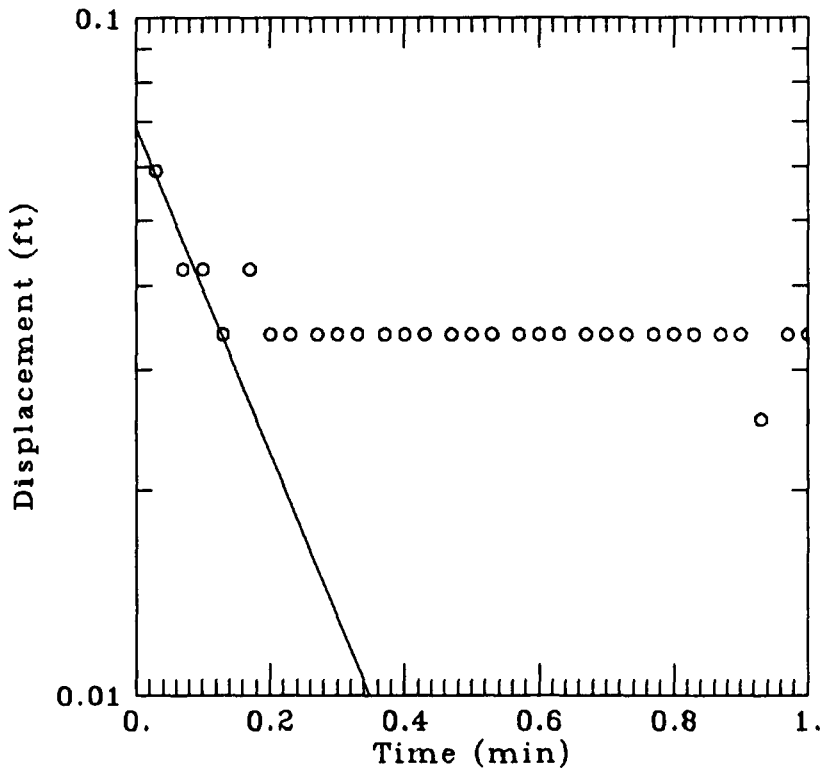
TEST DATA:

H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5. ft
b = 13.5 ft
H = 4.5 ft

FT-01, Well MW-155 Falling Head 1

Time	Head Change	Unit
0	0.4731	1
0.03	0.0507	1
0.07	0.0253	1
0.1	0.0169	1
0.13	0.0169	1
0.17	0.0084	1
0.2	0.0084	1
0.23	0.0084	1
0.27	0.0084	1
0.3	0.0084	1
0.33	0.0084	1
0.37	0.0084	1
0.4	0.0084	1
0.43	0.0084	1
0.47	0.0169	1
0.5	0.0084	1
0.53	0.0084	1
0.57	0.0084	1
0.6	0.0169	1
0.63	0.0084	1
0.67	0.0084	1
0.7	0.0084	1
0.73	0.0169	1
0.77	0.0084	1
0.8	0.0169	1
0.83	0.0084	1
0.87	0.0084	1
0.9	0.0169	1
0.93	0.0084	1
0.97	0.0084	1
1	0.0169	1
1.03	0.0084	1
1.07	0.0169	1
1.1	0.0169	1
1.13	0.0169	1
1.17	0.0169	1
1.2	0.0169	1
1.23	0.0169	1
1.27	0.0169	1
1.3	0.0169	1
1.33	0.0084	1
1.37	0.0169	1
1.4	0.0169	1

FT-01, Well MW-155 (Rising Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.006201 ft/min
y0 = 0.06865 ft

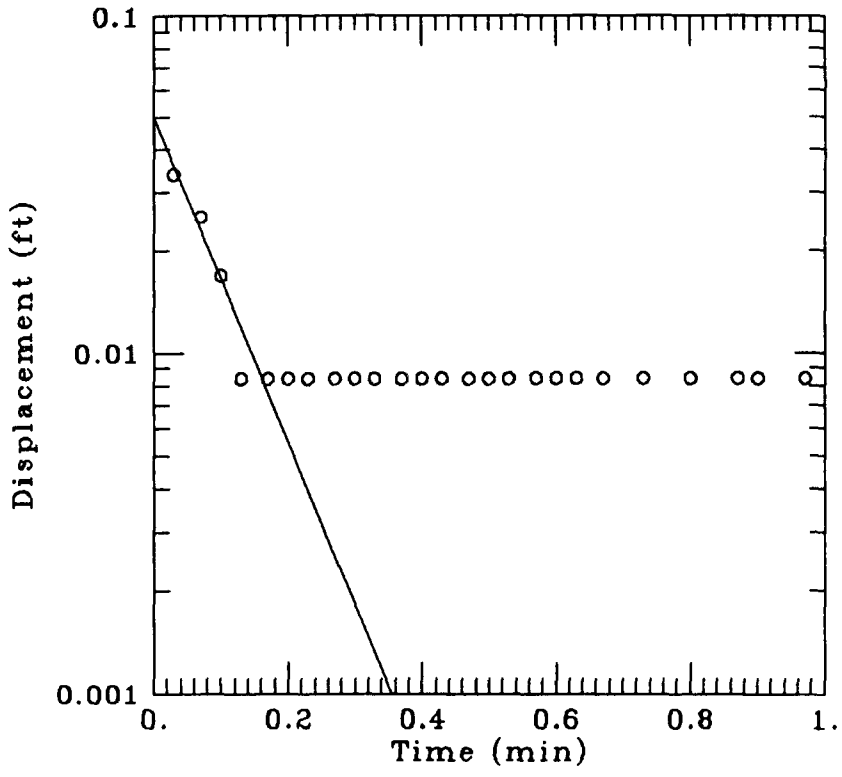
TEST DATA:

H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5. ft
b = 13.5 ft
H = 4.5 ft

FT-01, Well MW-155 Rising Head 1

Time	Head Change	Unit
0	0.2451	1
0.03	0.0592	1
0.07	0.0423	1
0.1	0.0423	1
0.13	0.0338	1
0.17	0.0423	1
0.2	0.0338	1
0.23	0.0338	1
0.27	0.0338	1
0.3	0.0338	1
0.33	0.0338	1
0.37	0.0338	1
0.4	0.0338	1
0.43	0.0338	1
0.47	0.0338	1
0.5	0.0338	1
0.53	0.0338	1
0.57	0.0338	1
0.6	0.0338	1
0.63	0.0338	1
0.67	0.0338	1
0.7	0.0338	1
0.73	0.0338	1
0.77	0.0338	1
0.8	0.0338	1
0.83	0.0338	1
0.87	0.0338	1
0.9	0.0338	1
0.93	0.0254	1
0.97	0.0338	1
1	0.0338	1
1.03	0.0338	1
1.07	0.0338	1
1.1	0.0338	1
1.13	0.0338	1
1.17	0.0254	1
1.2	0.0338	1
1.23	0.0338	1
1.27	0.0338	1
1.3	0.0338	1
1.33	0.0338	1
1.37	0.0254	1
1.4	0.0338	1
1.43	0.0338	1
1.47	0.0338	1
1.5	0.0338	1
1.53	0.0338	1

FT-01, Well MW-155 (Rising Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

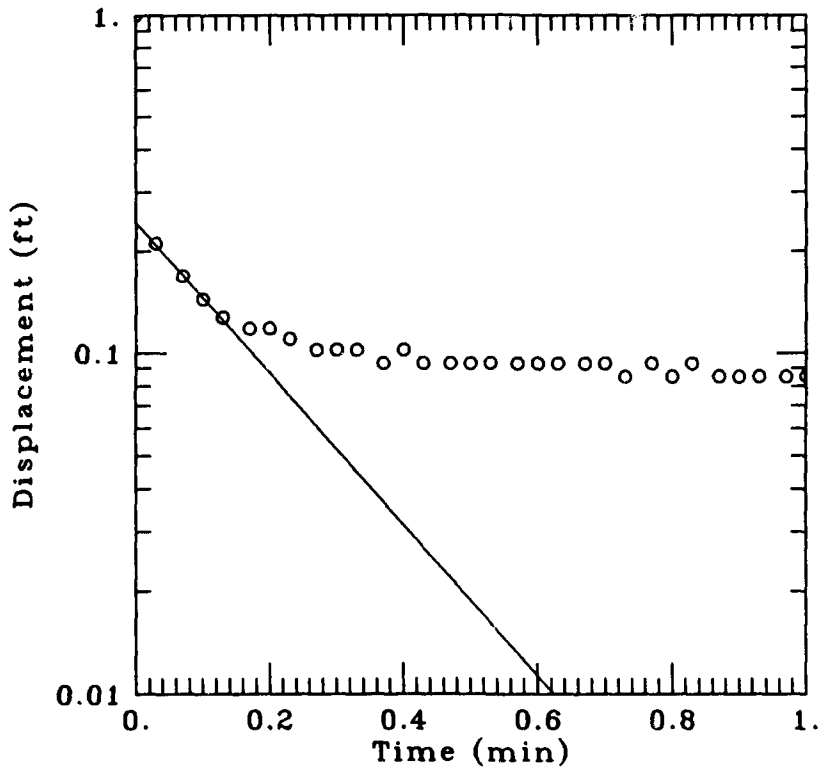
ESTIMATED PARAMETERS:
K = 0.01235 ft/min
y0 = 0.04993 ft

TEST DATA:
H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 5. ft
b = 13.5 ft
H = 4.5 ft

FT-01, Well MW-155 Rising Head 2

Time	Head Change	Unit
0	0.1436	1
0.03	0.0338	1
0.07	0.0253	1
0.1	0.0169	1
0.13	0.0084	1
0.17	0.0084	1
0.2	0.0084	1
0.23	0.0084	1
0.27	0.0084	1
0.3	0.0084	1
0.33	0.0084	1
0.37	0.0084	1
0.4	0.0084	1
0.43	0.0084	1
0.47	0.0084	1
0.5	0.0084	1
0.53	0.0084	1
0.57	0.0084	1
0.6	0.0084	1
0.63	0.0084	1
0.67	0.0084	1
0.7	0	1
0.73	0.0084	1
0.77	0	1
0.8	0.0084	1
0.83	0	1
0.87	0.0084	1
0.9	0.0084	1
0.93	0	1
0.97	0.0084	1
1	0	1
1.03	0.0084	1
1.07	0	1
1.1	0	1
1.13	0.0084	1
1.17	0	1
1.2	0.0084	1
1.23	0.0084	1
1.27	0.0084	1
1.3	0	1
1.33	0.0084	1
1.37	0.0084	1
1.4	0.0084	1

FT-01, Well MW-225 (Falling Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

K = 0.003921 ft/min
y0 = 0.2438 ft

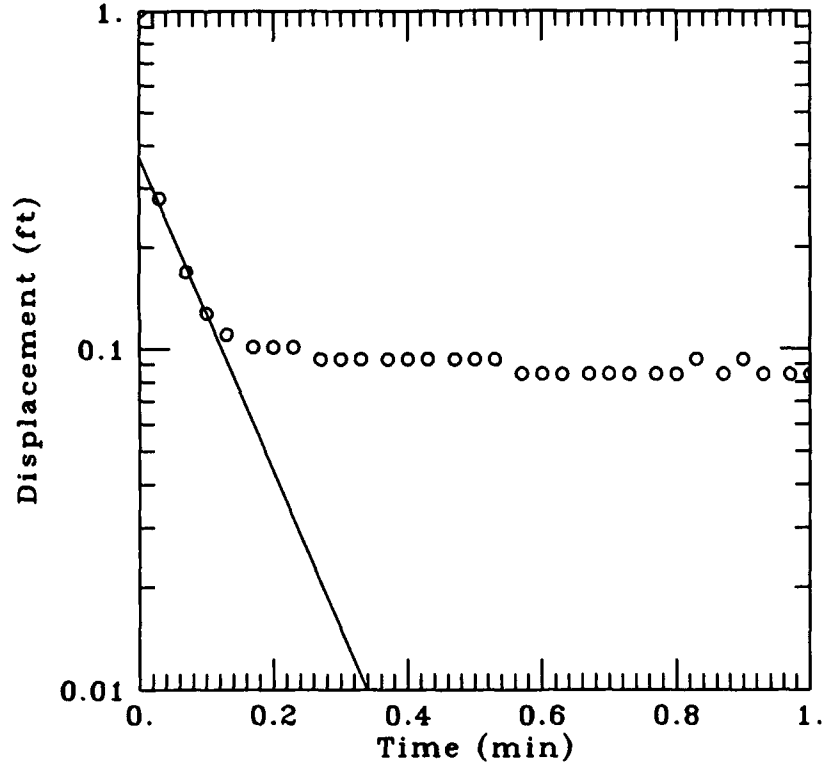
TEST DATA

H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10 ft
b = 25 ft
H = 10 ft

FT-01, Well MW-225 Falling Head 1

Time	Head Change	Unit
0	0.507	1
0.03	0.439	1
0.07	-0.051	1
0.1	0.084	1
0.13	0.152	1
0.17	0.186	1
0.2	0.194	1
0.23	0.211	1
0.27	0.211	1
0.3	0.211	1
0.33	0.211	1
0.37	0.22	1
0.4	0.22	1
0.43	0.22	1
0.47	0.22	1
0.5	0.22	1
0.53	0.22	1
0.57	0.22	1
0.6	0.22	1
0.63	0.22	1
0.67	0.228	1
0.7	0.228	1
0.73	0.22	1
0.77	0.228	1
0.8	0.22	1
0.83	0.228	1
0.87	0.228	1
0.9	0.22	1
0.93	0.228	1
0.97	0.228	1
1	0.228	1
1.03	0.22	1
1.07	0.22	1
1.1	0.22	1
1.13	0.228	1
1.17	0.228	1
1.2	0.22	1
1.23	0.22	1
1.27	0.22	1
1.3	0.228	1
1.33	0.22	1
1.37	0.228	1
1.4	0.228	1
1.43	0.228	1
1.47	0.228	1
1.5	0.228	1
1.53	0.228	1

FT-01, Well MW-225 (Rising Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.008153 ft/min
y0 = 0.3707 ft

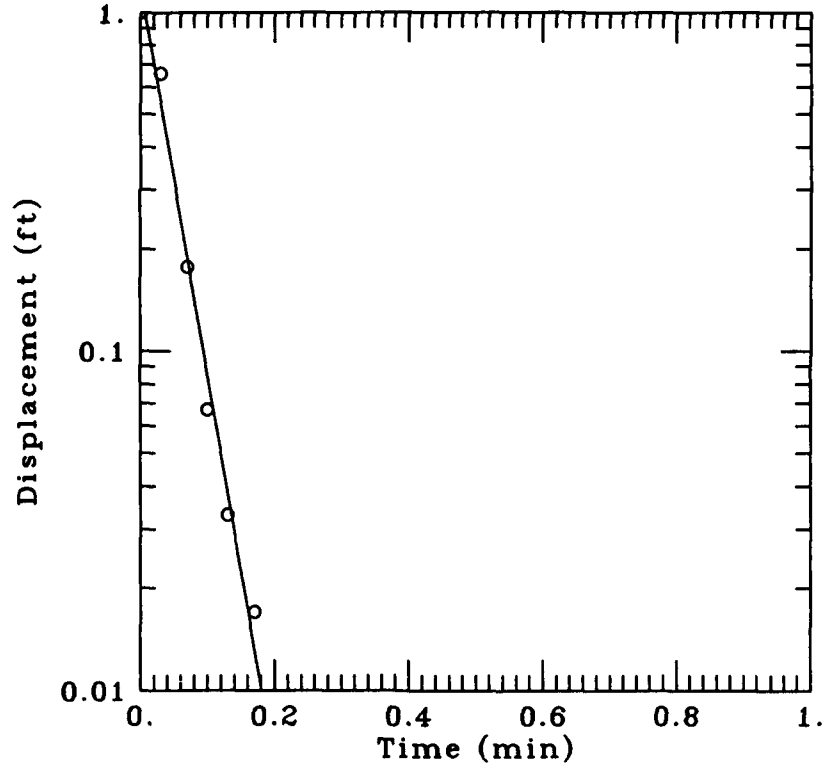
TEST DATA:

H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10. ft
b = 25. ft
H = 10. ft

FT-01, Well MW-225 Rising Head 1

Time	Head Change	Unit
0	0.659	1
0.03	0.279	1
0.07	0.169	1
0.1	0.127	1
0.13	0.11	1
0.17	0.101	1
0.2	0.101	1
0.23	0.101	1
0.27	0.093	1
0.3	0.093	1
0.33	0.093	1
0.37	0.093	1
0.4	0.093	1
0.43	0.093	1
0.47	0.093	1
0.5	0.093	1
0.53	0.093	1
0.57	0.084	1
0.6	0.084	1
0.63	0.084	1
0.67	0.084	1
0.7	0.084	1
0.73	0.084	1
0.77	0.084	1
0.8	0.084	1
0.83	0.093	1
0.87	0.084	1
0.9	0.093	1
0.93	0.084	1
0.97	0.084	1
1	0.084	1
1.03	0.084	1
1.07	0.093	1
1.1	0.084	1
1.13	0.084	1
1.17	0.093	1
1.2	0.093	1
1.23	0.093	1
1.27	0.093	1
1.3	0.093	1
1.33	0.093	1
1.37	0.093	1
1.4	0.093	1

FT-01, Well MW-225 (Rising Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.02023 ft/min
y0 = 1.19 ft

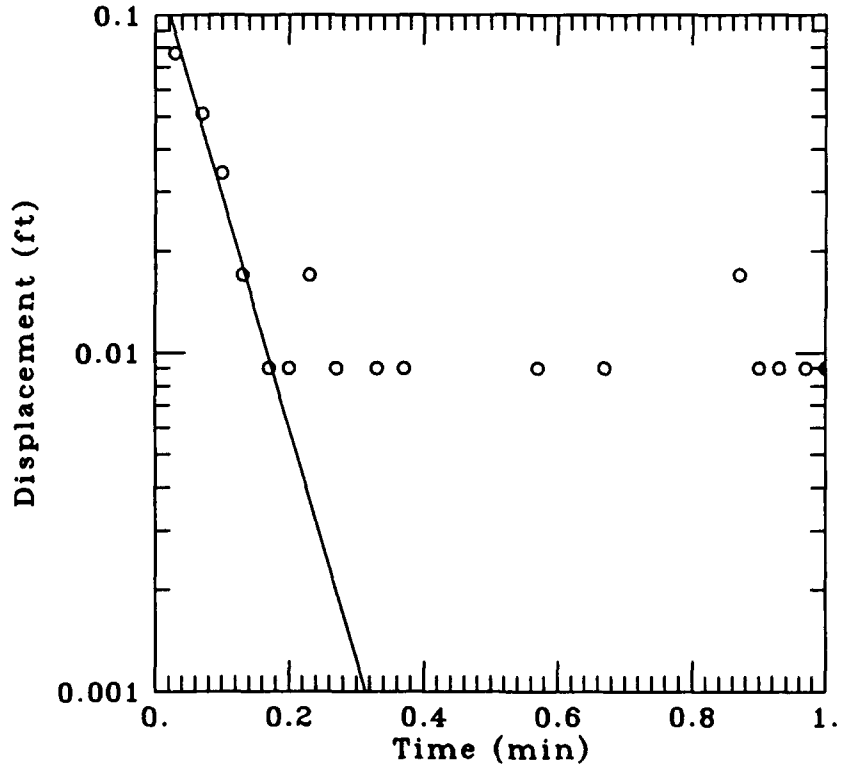
TEST DATA:

H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10. ft
b = 25. ft
H = 10. ft

FT-01, Well MW-225 Rising Head 2

Time	Head Change	Unit
0	13.121	1
0.03	0.659	1
0.07	0.177	1
0.1	0.067	1
0.13	0.033	1
0.17	0.017	1
0.2	0.008	1
0.23	0	1
0.27	0	1
0.3	-0.009	1
0.33	-0.009	1
0.37	-0.009	1
0.4	-0.009	1
0.43	-0.009	1
0.47	-0.009	1
0.5	-0.009	1
0.53	-0.009	1
0.57	-0.017	1
0.6	-0.009	1
0.63	-0.009	1
0.67	-0.009	1
0.7	-0.009	1
0.73	-0.017	1
0.77	-0.017	1
0.8	-0.009	1
0.83	-0.009	1
0.87	-0.017	1
0.9	-0.017	1
0.93	-0.017	1
0.97	-0.017	1
1	-0.017	1
1.03	-0.009	1
1.07	-0.009	1
1.1	-0.009	1

FT-01, Well MW-226 (Falling Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.0121 ft/min
y0 = 0.1406 ft

TEST DATA:

H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10 ft
b = 25 ft
H = 10 ft

226

FT-01, Well MW-1 Falling Head 1

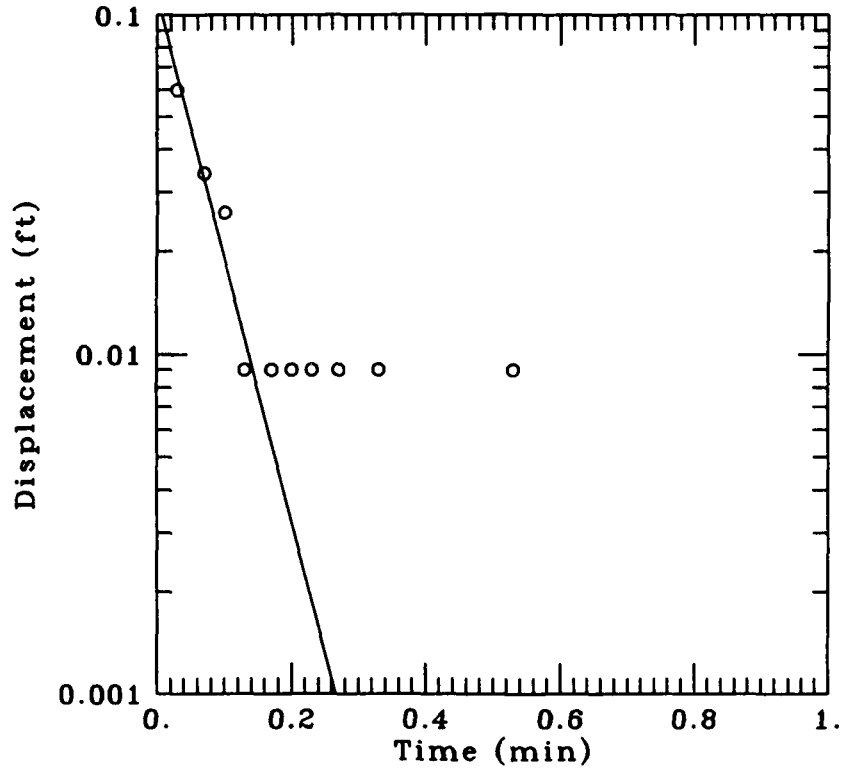
Time	Head Change	Unit
0	0.33	1
0.03	0.077	1
0.07	0.051	1
0.1	0.034	1
0.13	0.017	1
0.17	0.009	1
0.2	0.009	1
0.23	0.017	1
0.27	0.009	1
0.3	0	1
0.33	0.009	1
0.37	0.009	1
0.4	0	1
0.43	0	1
0.47	-0.008	1
0.5	0	1
0.53	0	1
0.57	0.009	1
0.6	0	1
0.63	0	1
0.67	0.009	1
0.7	0	1
0.73	0	1
0.77	-0.008	1
0.8	-0.008	1
0.83	-0.016	1
0.87	0.017	1
0.9	0.009	1
0.93	0.009	1
0.97	0.009	1
1	0.009	1
1.03	0.017	1
1.07	0.009	1
1.1	0	1
1.13	0	1
1.17	0.009	1
1.2	0	1
1.23	0	1
1.27	0.009	1
1.3	0	1
1.33	0.009	1
1.37	-0.025	1
1.4	-0.025	1
1.43	-0.025	1
1.47	-0.016	1
1.5	-0.016	1
1.53	-0.008	1

226

FT-01, Well MW-4 Falling Head 1

Time	Head Change	Unit
1.57	-0.008	1
1.6	-0.008	1
1.63	-0.016	1
1.67	-0.008	1
1.7	-0.016	1
1.73	-0.008	1
1.77	-0.016	1
1.8	-0.025	1
1.83	-0.025	1
1.87	-0.025	1
1.9	-0.025	1
1.93	-0.025	1
1.97	-0.025	1
2	0.017	1
2.03	0.017	1
2.07	0.017	1
2.1	-0.008	1
2.13	-0.008	1
2.17	-0.008	1
2.2	-0.016	1
2.23	-0.016	1
2.27	-0.016	1
2.3	-0.016	1
2.33	-0.025	1
2.37	-0.016	1
2.4	-0.025	1
2.43	-0.025	1
2.47	-0.025	1
2.5	-0.016	1
2.53	-0.025	1
2.57	-0.016	1
2.6	-0.016	1
2.63	-0.016	1
2.67	-0.016	1
2.7	-0.016	1
2.73	-0.016	1
2.77	-0.016	1
2.8	-0.016	1
2.83	-0.016	1
2.87	-0.025	1
2.9	-0.025	1
2.93	-0.016	1
2.97	-0.016	1
3	-0.025	1
3.03	-0.016	1

FT-01, Well MW-226 (Falling Head Test 2)



DATA SET

10/09/97

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

K = 0.01366 ft/min
y0 = 0.1145 ft

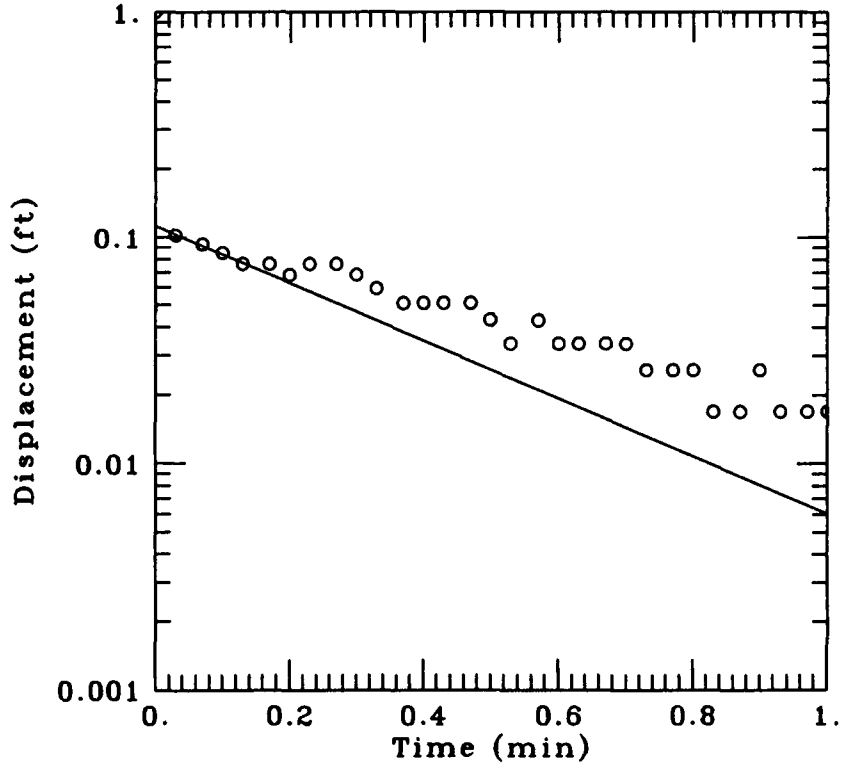
TEST DATA

H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10. ft
b = 25. ft
H = 10. ft

FT-01, Well MW-1 Falling Head 2

Time	Head Change	Unit
0	0.153	1
0.03	0.06	1
0.07	0.034	1
0.1	0.026	1
0.13	0.009	1
0.17	0.009	1
0.2	0.009	1
0.23	0.009	1
0.27	0.009	1
0.3	0	1
0.33	0.009	1
0.37	0	1
0.4	0	1
0.43	0	1
0.47	0	1
0.5	0	1
0.53	0.009	1
0.57	0	1
0.6	0	1
0.63	0	1
0.67	0	1
0.7	0	1
0.73	0	1
0.77	0	1
0.8	0	1
0.83	0	1
0.87	0	1
0.9	0	1
0.93	0	1
0.97	0	1
1	-0.008	1
1.03	0	1
1.07	0	1
1.1	0	1
1.13	0	1
1.17	0	1
1.2	-0.008	1
1.23	0	1
1.27	0	1
1.3	0	1
1.33	-0.008	1
1.37	-0.008	1
1.4	0	1
1.43	0	1
1.47	-0.008	1

FT-01, Well MW-226 (Rising Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.00224 ft/min
y0 = 0.1126 ft

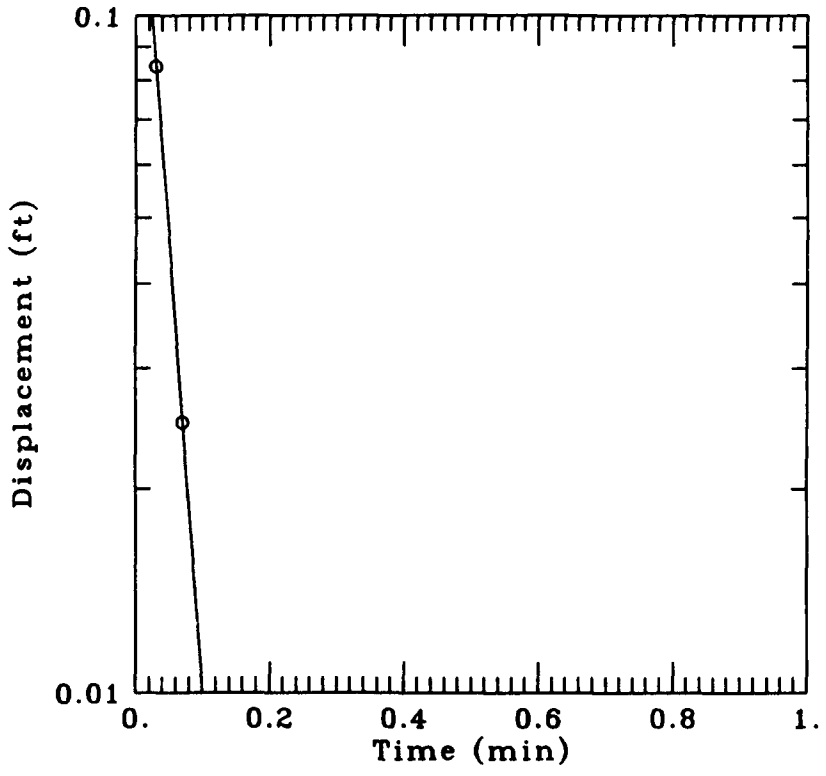
TEST DATA:

H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10 ft
b = 25 ft
H = 10 ft

FT-01, Well MW-1 Rising Head 1

Time	Head Change	Unit
0	0.093	1
0.03	0.102	1
0.07	0.093	1
0.1	0.085	1
0.13	0.076	1
0.17	0.076	1
0.2	0.068	1
0.23	0.076	1
0.27	0.076	1
0.3	0.068	1
0.33	0.059	1
0.37	0.051	1
0.4	0.051	1
0.43	0.051	1
0.47	0.051	1
0.5	0.043	1
0.53	0.034	1
0.57	0.043	1
0.6	0.034	1
0.63	0.034	1
0.67	0.034	1
0.7	0.034	1
0.73	0.026	1
0.77	0.026	1
0.8	0.026	1
0.83	0.017	1
0.87	0.017	1
0.9	0.026	1
0.93	0.017	1
0.97	0.017	1
1	0.017	1
1.03	0.017	1
1.07	0.009	1
1.1	0.009	1
1.13	0.009	1
1.17	0.009	1
1.2	0.009	1
1.23	0.009	1
1.27	0.009	1
1.3	0.009	1
1.33	0.009	1
1.37	0.009	1
1.4	0.009	1
1.43	0.009	1
1.47	0	1
1.5	0	1
1.53	0	1

FT-01, Well MW-226 (Rising Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE

Unconfined

SOLUTION METHOD

Bouwer-Rice

ESTIMATED PARAMETERS

K = 0.02321 ft/min
y0 = 0.2085 ft

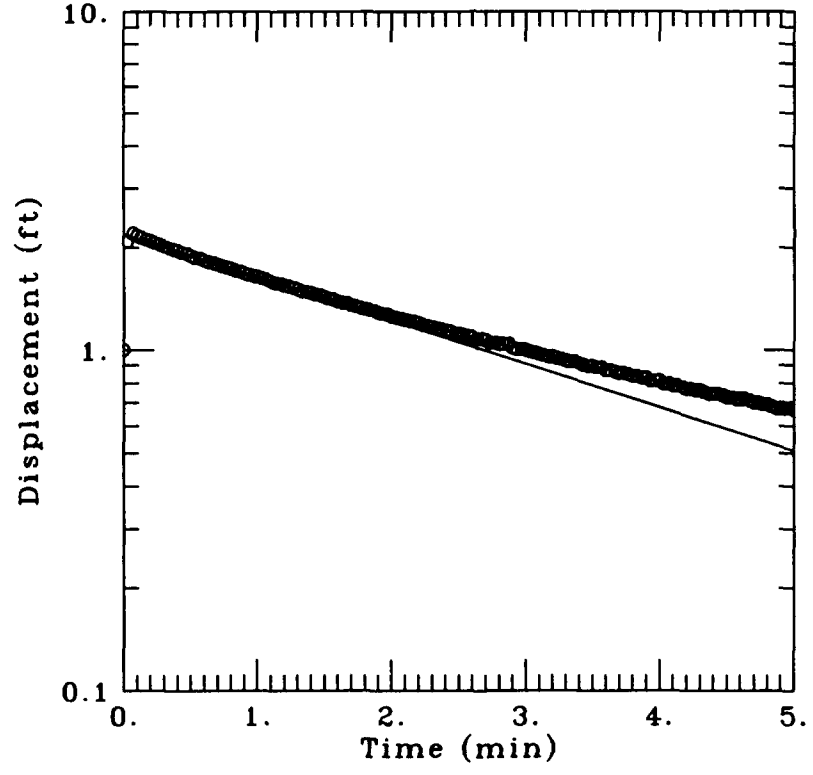
TEST DATA

H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10 ft
b = 25 ft
H = 10 ft

FT-01, Well MW-1 Rising Head 2

Time	Head Change	Unit
0	0.219	1
0.03	0.084	1
0.07	0.025	1
0.1	0	1
0.13	-0.009	1
0.17	-0.017	1
0.2	-0.017	1
0.23	-0.017	1
0.27	-0.009	1
0.3	-0.017	1
0.33	-0.017	1
0.37	-0.009	1
0.4	-0.009	1
0.43	-0.009	1
0.47	-0.009	1
0.5	-0.009	1
0.53	-0.009	1
0.57	-0.009	1
0.6	-0.009	1
0.63	-0.009	1
0.67	-0.009	1
0.7	-0.009	1
0.73	-0.009	1
0.77	-0.009	1
0.8	0	1
0.83	0	1
0.87	0	1
0.9	0	1
0.93	-0.009	1
0.97	0	1
1	0	1

FT-01, Well MW-227 (Falling Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 0.000224 ft/min
y0 = 2.189 ft

TEST DATA:
H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10. ft
b = 25. ft
H = 10. ft

FT-01, Well MW-227 Falling Head 1

Time	Head Change	Unit
0	2.256	1
0.03	2.087	1
0.07	2.205	1
0.1	2.171	1
0.13	2.146	1
0.17	2.112	1
0.2	2.095	1
0.23	2.07	1
0.27	2.044	1
0.3	2.019	1
0.33	2.002	1
0.37	1.977	1
0.4	1.96	1
0.43	1.934	1
0.47	1.918	1
0.5	1.892	1
0.53	1.867	1
0.57	1.858	1
0.6	1.833	1
0.63	1.816	1
0.67	1.799	1
0.7	1.782	1
0.73	1.766	1
0.77	1.749	1
0.8	1.732	1
0.83	1.715	1
0.87	1.698	1
0.9	1.681	1
0.93	1.664	1
0.97	1.647	1
1	1.639	1
1.03	1.622	1
1.07	1.605	1
1.1	1.588	1
1.13	1.571	1
1.17	1.563	1
1.2	1.546	1
1.23	1.537	1
1.27	1.52	1
1.3	1.504	1
1.33	1.487	1
1.37	1.478	1
1.4	1.47	1
1.43	1.453	1
1.47	1.444	1
1.5	1.428	1
1.53	1.411	1

FT-01, Well MW-227 Falling Head 1

Time	Head Change	Unit
1.57	1.402	1
1.6	1.385	1
1.63	1.377	1
1.67	1.368	1
1.7	1.351	1
1.73	1.343	1
1.77	1.326	1
1.8	1.318	1
1.83	1.309	1
1.87	1.301	1
1.9	1.284	1
1.93	1.275	1
1.97	1.267	1
2	1.25	1
2.03	1.242	1
2.07	1.233	1
2.1	1.225	1
2.13	1.216	1
2.17	1.208	1
2.2	1.199	1
2.23	1.183	1
2.27	1.174	1
2.3	1.166	1
2.33	1.157	1
2.37	1.149	1
2.4	1.14	1
2.43	1.132	1
2.47	1.115	1
2.5	1.115	1
2.53	1.106	1
2.57	1.098	1
2.6	1.09	1
2.63	1.073	1
2.67	1.073	1
2.7	1.064	1
2.73	1.047	1
2.77	1.047	1
2.8	1.039	1
2.83	1.039	1
2.87	1.039	1
2.9	1.014	1
2.93	1.005	1
2.97	1.005	1
3	0.997	1
3.03	0.988	1
3.07	0.98	1
3.1	0.971	1

FT-01, Well MW-227 Falling Head 1

Time	Head Change	Unit
3.13	0.963	1
3.17	0.954	1
3.2	0.954	1
3.23	0.946	1
3.27	0.937	1
3.3	0.929	1
3.33	0.921	1
3.37	0.921	1
3.4	0.912	1
3.43	0.904	1
3.47	0.895	1
3.5	0.895	1
3.53	0.887	1
3.57	0.887	1
3.6	0.87	1
3.63	0.87	1
3.67	0.861	1
3.7	0.853	1
3.73	0.853	1
3.77	0.845	1
3.8	0.836	1
3.83	0.836	1
3.87	0.828	1
3.9	0.828	1
3.93	0.811	1
3.97	0.811	1
4	0.811	1
4.03	0.794	1
4.07	0.794	1
4.1	0.785	1
4.13	0.785	1
4.17	0.777	1
4.2	0.768	1
4.23	0.768	1
4.27	0.76	1
4.3	0.76	1
4.33	0.752	1
4.37	0.743	1
4.4	0.743	1
4.43	0.743	1
4.47	0.735	1
4.5	0.726	1
4.53	0.726	1
4.57	0.718	1
4.6	0.718	1
4.63	0.718	1
4.67	0.709	1

FT-01, Well MW-227 Falling Head 1

Time	Head Change	Unit
4.7	0.701	1
4.73	0.701	1
4.77	0.692	1
4.8	0.692	1
4.83	0.684	1
4.87	0.676	1
4.9	0.676	1
4.93	0.676	1
4.97	0.676	1
5	0.667	1
5.03	0.667	1
5.07	0.659	1
5.1	0.65	1
5.13	0.659	1
5.17	0.65	1
5.2	0.65	1
5.23	0.642	1
5.27	0.633	1
5.3	0.633	1
5.33	0.625	1
5.37	0.625	1
5.4	0.625	1
5.43	0.616	1
5.47	0.616	1
5.5	0.616	1
5.53	0.608	1
5.57	0.608	1
5.6	0.6	1
5.63	0.6	1
5.67	0.6	1
5.7	0.591	1
5.73	0.583	1
5.77	0.583	1
5.8	0.583	1
5.83	0.583	1
5.87	0.574	1
5.9	0.574	1
5.93	0.574	1
5.97	0.566	1
6	0.566	1
6.03	0.566	1
6.07	0.557	1
6.1	0.557	1
6.13	0.549	1
6.17	0.549	1
6.2	0.549	1
6.23	0.54	1

FT-01, Well MW-227 Falling Head 1

Time	Head Change	Unit
6.27	0.549	1
6.3	0.54	1
6.33	0.54	1
6.37	0.532	1
6.4	0.532	1
6.43	0.532	1
6.47	0.523	1
6.5	0.532	1
6.53	0.523	1
6.57	0.515	1
6.6	0.515	1
6.63	0.515	1
6.67	0.515	1
6.7	0.507	1
6.73	0.507	1
6.77	0.507	1
6.8	0.507	1
6.83	0.498	1
6.87	0.507	1
6.9	0.498	1
6.93	0.498	1
6.97	0.49	1
7	0.49	1
7.03	0.49	1
7.07	0.49	1
7.1	0.481	1
7.13	0.481	1
7.17	0.473	1
7.2	0.473	1
7.23	0.481	1
7.27	0.473	1
7.3	0.473	1
7.33	0.464	1
7.37	0.464	1
7.4	0.464	1
7.43	0.464	1
7.47	0.464	1
7.5	0.464	1
7.53	0.456	1
7.57	0.456	1
7.6	0.456	1
7.63	0.456	1
7.67	0.447	1
7.7	0.447	1
7.73	0.439	1
7.77	0.447	1
7.8	0.439	1

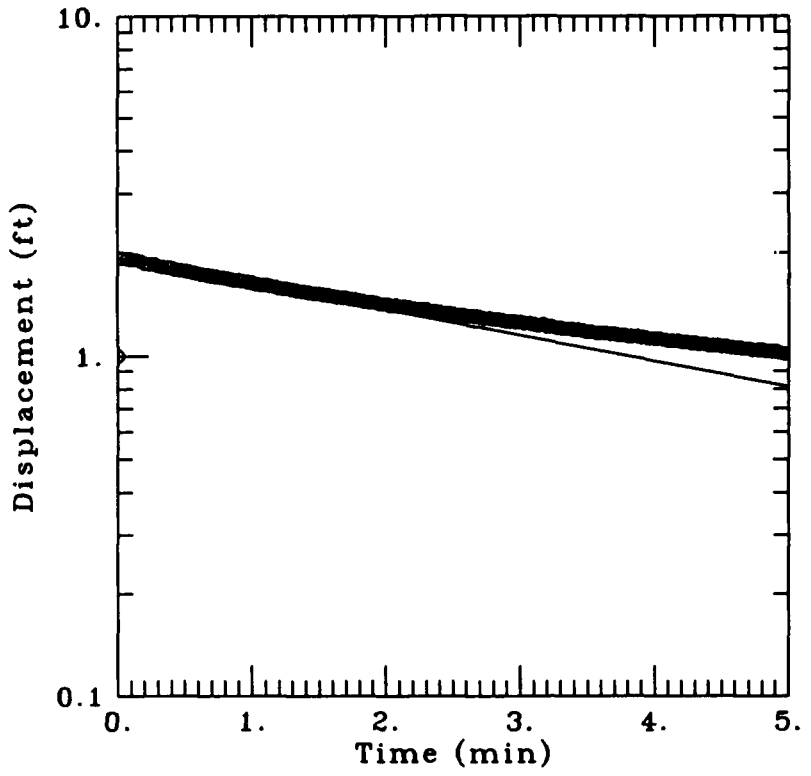
FT-01, Well MW-227 Falling Head 1

Time	Head Change	Unit
7.83	0.439	1
7.87	0.439	1
7.9	0.439	1
7.93	0.431	1
7.97	0.431	1
8	0.431	1
8.03	0.431	1
8.07	0.431	1
8.1	0.431	1
8.13	0.422	1
8.17	0.422	1
8.2	0.422	1
8.23	0.422	1
8.27	0.414	1
8.3	0.422	1
8.33	0.414	1
8.37	0.414	1
8.4	0.414	1
8.43	0.414	1
8.47	0.414	1
8.5	0.405	1
8.53	0.405	1
8.57	0.405	1
8.6	0.405	1
8.63	0.397	1
8.67	0.405	1
8.7	0.405	1
8.73	0.397	1
8.77	0.405	1
8.8	0.397	1
8.83	0.397	1
8.87	0.397	1
8.9	0.388	1
8.93	0.388	1
8.97	0.388	1
9	0.388	1
9.03	0.388	1
9.07	0.388	1
9.1	0.388	1
9.13	0.38	1
9.17	0.38	1
9.2	0.38	1
9.23	0.38	1
9.27	0.371	1
9.3	0.38	1
9.33	0.38	1
9.37	0.371	1

FT-01, Well MW-227 Falling Head 1

Time	Head Change	Unit
9.4	0.38	1
9.43	0.371	1
9.47	0.371	1
9.5	0.371	1
9.53	0.371	1
9.57	0.371	1
9.6	0.371	1
9.63	0.371	1

FT-01, Well MW-227 (Falling Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:

Unconfined

SOLUTION METHOD:

Bouwer-Rice

ESTIMATED PARAMETERS:

K = 0.0001338 ft/min
y0 = 1.941 ft

TEST DATA:

H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10. ft
b = 25. ft
H = 10. ft

FT-01, Well MW-227 Falling Head 2

Time	Head Change	Unit
0	1.85	1
0.03	1.935	1
0.07	1.927	1
0.1	1.91	1
0.13	1.91	1
0.17	1.893	1
0.2	1.867	1
0.23	1.859	1
0.27	1.859	1
0.3	1.834	1
0.33	1.825	1
0.37	1.817	1
0.4	1.808	1
0.43	1.791	1
0.47	1.783	1
0.5	1.774	1
0.53	1.766	1
0.57	1.749	1
0.6	1.741	1
0.63	1.732	1
0.67	1.724	1
0.7	1.715	1
0.73	1.707	1
0.77	1.698	1
0.8	1.69	1
0.83	1.681	1
0.87	1.665	1
0.9	1.665	1
0.93	1.656	1
0.97	1.648	1
1	1.639	1
1.03	1.622	1
1.07	1.614	1
1.1	1.614	1
1.13	1.605	1
1.17	1.597	1
1.2	1.58	1
1.23	1.572	1
1.27	1.572	1
1.3	1.563	1
1.33	1.555	1
1.37	1.546	1
1.4	1.538	1
1.43	1.529	1
1.47	1.521	1
1.5	1.521	1
1.53	1.513	1

FT-01, Well MW-227 Falling Head 2

Time	Head Change	Unit
1.57	1.504	1
1.6	1.496	1
1.63	1 487	1
1.67	1.479	1
1.7	1.479	1
1.73	1.47	1
1.77	1.462	1
1.8	1.453	1
1.83	1.445	1
1.87	1.436	1
1.9	1.436	1
1.93	1.428	1
1.97	1.42	1
2	1.42	1
2.03	1.403	1
2.07	1.403	1
2.1	1.394	1
2.13	1.394	1
2.17	1.386	1
2.2	1.377	1
2.23	1.369	1
2.27	1.369	1
2.3	1.369	1
2.33	1.352	1
2.37	1.352	1
2.4	1.344	1
2.43	1.335	1
2.47	1.335	1
2.5	1.327	1
2.53	1.318	1
2.57	1.318	1
2.6	1.31	1
2.63	1.31	1
2.67	1.301	1
2.7	1.293	1
2.73	1.284	1
2.77	1.284	1
2.8	1.276	1
2.83	1.276	1
2.87	1.267	1
2.9	1.259	1
2.93	1.259	1
2.97	1.251	1
3	1.251	1
3.03	1.242	1
3.07	1.242	1
3.1	1.234	1

FT-01, Well MW-227 Falling Head 2

Time	Head Change	Unit
3.13	1.225	1
3.17	1.234	1
3.2	1.217	1
3.23	1.217	1
3.27	1.208	1
3.3	1.208	1
3.33	1.2	1
3.37	1.2	1
3.4	1.191	1
3.43	1.191	1
3.47	1.183	1
3.5	1.175	1
3.53	1.175	1
3.57	1.166	1
3.6	1.166	1
3.63	1.166	1
3.67	1.158	1
3.7	1.158	1
3.73	1.149	1
3.77	1.149	1
3.8	1.141	1
3.83	1.141	1
3.87	1.141	1
3.9	1.132	1
3.93	1.132	1
3.97	1.124	1
4	1.124	1
4.03	1.124	1
4.07	1.115	1
4.1	1.107	1
4.13	1.107	1
4.17	1.107	1
4.2	1.098	1
4.23	1.098	1
4.27	1.09	1
4.3	1.09	1
4.33	1.082	1
4.37	1.082	1
4.4	1.073	1
4.43	1.073	1
4.47	1.073	1
4.5	1.065	1
4.53	1.065	1
4.57	1.056	1
4.6	1.056	1
4.63	1.056	1
4.67	1.048	1

FT-01, Well MW-227 Falling Head 2

Time	Head Change	Unit
4.7	1.048	1
4.73	1.039	1
4.77	1.039	1
4.8	1.039	1
4.83	1.031	1
4.87	1.031	1
4.9	1.031	1
4.93	1.022	1
4.97	1.014	1
5	1.014	1
5.03	1.014	1
5.07	1.014	1
5.1	1.006	1
5.13	1.006	1
5.17	1.006	1
5.2	0.997	1
5.23	0.997	1
5.27	0.989	1
5.3	0.989	1
5.33	0.989	1
5.37	0.989	1
5.4	0.989	1
5.43	0.98	1
5.47	0.972	1
5.5	0.972	1
5.53	0.972	1
5.57	0.972	1
5.6	0.963	1
5.63	0.963	1
5.67	0.963	1
5.7	0.963	1
5.73	0.955	1
5.77	0.955	1
5.8	0.955	1
5.83	0.955	1
5.87	0.946	1
5.9	0.946	1
5.93	0.938	1
5.97	0.938	1
6	0.938	1
6.03	0.938	1
6.07	0.93	1
6.1	0.93	1
6.13	0.921	1
6.17	0.921	1
6.2	0.93	1
6.23	0.921	1

FT-01, Well MW-227 Falling Head 2

Time	Head Change	Unit
6.27	0.921	1
6.3	0.921	1
6.33	0.913	1
6.37	0.913	1
6.4	0.913	1
6.43	0.904	1
6.47	0.904	1
6.5	0.904	1
6.53	0.896	1
6.57	0.904	1
6.6	0.896	1
6.63	0.896	1
6.67	0.887	1
6.7	0.887	1
6.73	0.887	1
6.77	0.879	1
6.8	0.879	1
6.83	0.879	1
6.87	0.879	1
6.9	0.879	1
6.93	0.87	1
6.97	0.87	1
7	0.87	1
7.03	0.87	1
7.07	0.87	1
7.1	0.862	1
7.13	0.862	1
7.17	0.862	1
7.2	0.862	1
7.23	0.862	1
7.27	0.853	1
7.3	0.853	1
7.33	0.853	1
7.37	0.845	1
7.4	0.845	1
7.43	0.845	1
7.47	0.845	1
7.5	0.845	1
7.53	0.837	1
7.57	0.837	1
7.6	0.837	1
7.63	0.837	1
7.67	0.837	1
7.7	0.837	1
7.73	0.828	1
7.77	0.828	1
7.8	0.828	1

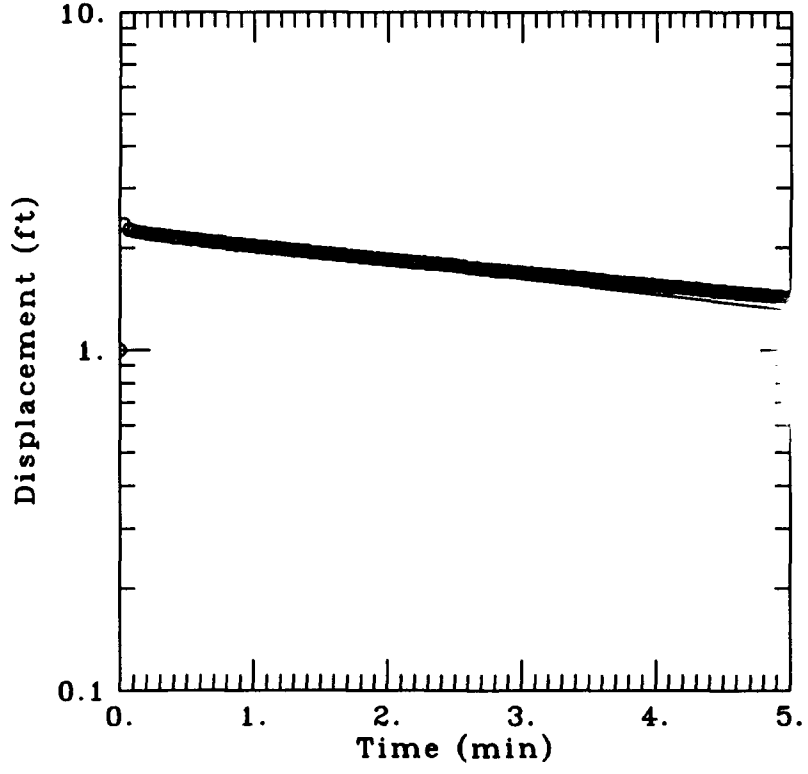
FT-01, Well MW-227 Falling Head 2

Time	Head Change	Unit
7.83	0.828	1
7.87	0.828	1
7.9	0.828	1
7.93	0.828	1
7.97	0.82	1
8	0.82	1
8.03	0.82	1
8.07	0.82	1
8.1	0.82	1
8.13	0.811	1
8.17	0.811	1
8.2	0.811	1
8.23	0.811	1
8.27	0.811	1
8.3	0.811	1
8.33	0.803	1
8.37	0.803	1
8.4	0.803	1
8.43	0.803	1
8.47	0.794	1
8.5	0.794	1
8.53	0.794	1
8.57	0.786	1
8.6	0.794	1
8.63	0.794	1
8.67	0.794	1
8.7	0.786	1
8.73	0.794	1
8.77	0.786	1
8.8	0.786	1
8.83	0.786	1
8.87	0.777	1
8.9	0.786	1
8.93	0.777	1
8.97	0.777	1
9	0.777	1
9.03	0.769	1
9.07	0.777	1
9.1	0.777	1
9.13	0.777	1
9.17	0.769	1
9.2	0.769	1
9.23	0.769	1
9.27	0.769	1
9.3	0.769	1
9.33	0.769	1
9.37	0.761	1

FT-01, Well MW-227 Falling Head 2

Time	Head Change	Unit
9.4	0.761	1
9.43	0.769	1
9.47	0.761	1
9.5	0.761	1
9.53	0.761	1
9.57	0.761	1
9.6	0.761	1
9.63	0.752	1
9.67	0.752	1
9.7	0.752	1
9.73	0.752	1
9.77	0.752	1
9.8	0.744	1
9.83	0.744	1
9.87	0.744	1
9.9	0.744	1
9.93	0.744	1
9.97	0.744	1
10	0.735	1
10.03	0.744	1
10.07	0.735	1
10.1	0.744	1
10.13	0.735	1
10.17	0.744	1
10.2	0.735	1
10.23	0.735	1
10.27	0.735	1
10.3	0.735	1
10.33	0.735	1
10.37	0.735	1
10.4	0.735	1
10.43	0.727	1
10.47	0.727	1
10.5	0.727	1
10.53	0.727	1
10 57	0.727	1
10.6	0.727	1
10.63	0.727	1
10.67	0.718	1
10.7	0.718	1
10.73	0.727	1
10.77	0.718	1
10.8	0.718	1

FT-01, Well MW-227 (Rising Head Test 1)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

ESTIMATED PARAMETERS:
K = 8.4395E-05 ft/min
y0 = 2.26 ft

TEST DATA:
H0 = 1. ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10. ft
b = 25. ft
H = 10. ft

FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
0	5.39	1
0.03	2.3482	1
0.07	2.2637	1
0.1	2.2468	1
0.13	2.2299	1
0.17	2.2215	1
0.2	2.2046	1
0.23	2.1961	1
0.27	2.1877	1
0.3	2.1792	1
0.33	2.1708	1
0.37	2.1624	1
0.4	2.1455	1
0.43	2.1455	1
0.47	2.137	1
0.5	2.1286	1
0.53	2.1201	1
0.57	2.1117	1
0.6	2.1032	1
0.63	2.0948	1
0.67	2.0863	1
0.7	2.0779	1
0.73	2.0779	1
0.77	2.0694	1
0.8	2.061	1
0.83	2.0525	1
0.87	2.0441	1
0.9	2.0441	1
0.93	2.0356	1
0.97	2.0272	1
1	2.0272	1
1.03	2.0103	1
1.07	2.0103	1
1.1	2.0018	1
1.13	1.9934	1
1.17	1.9934	1
1.2	1.9849	1
1.23	1.9765	1
1.27	1.968	1
1.3	1.9596	1
1.33	1.9596	1
1.37	1.9511	1
1.4	1.9511	1
1.43	1.9342	1
1.47	1.9342	1
1.5	1.9258	1
1.53	1.9173	1

FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
1.57	1.9173	1
1.6	1.9089	1
1.63	1.9004	1
1.67	1.9004	1
1.7	1.892	1
1.73	1.892	1
1.77	1.8835	1
1.8	1.8751	1
1.83	1.8751	1
1.87	1.8666	1
1.9	1.8582	1
1.93	1.8582	1
1.97	1.8497	1
2	1.8413	1
2.03	1.8413	1
2.07	1.8328	1
2.1	1.8244	1
2.13	1.8244	1
2.17	1.8159	1
2.2	1.8075	1
2.23	1.8075	1
2.27	1.8075	1
2.3	1.7906	1
2.33	1.7906	1
2.37	1.7906	1
2.4	1.7821	1
2.43	1.7737	1
2.47	1.7737	1
2.5	1.7652	1
2.53	1.7568	1
2.57	1.7568	1
2.6	1.7483	1
2.63	1.7483	1
2.67	1.7399	1
2.7	1.7314	1
2.73	1.7314	1
2.77	1.723	1
2.8	1.7145	1
2.83	1.7145	1
2.87	1.7061	1
2.9	1.7061	1
2.93	1.6976	1
2.97	1.6976	1
3	1.6892	1
3.03	1.6807	1
3.07	1.6807	1
3.1	1.6723	1

FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
3.13	1.6723	1
3.17	1.6638	1
3.2	1.6638	1
3.23	1.6554	1
3.27	1.6469	1
3.3	1.6469	1
3.33	1.6385	1
3.37	1.6385	1
3.4	1.63	1
3.43	1.622	1
3.47	1.622	1
3.5	1.614	1
3.53	1.614	1
3.57	1.605	1
3.6	1.605	1
3.63	1.597	1
3.67	1.588	1
3.7	1.588	1
3.73	1.58	1
3.77	1.58	1
3.8	1.571	1
3.83	1.571	1
3.87	1.563	1
3.9	1.563	1
3.93	1.554	1
3.97	1.554	1
4	1.546	1
4.03	1.546	1
4.07	1.538	1
4.1	1.529	1
4.13	1.529	1
4.17	1.529	1
4.2	1.521	1
4.23	1.521	1
4.27	1.512	1
4.3	1.512	1
4.33	1.504	1
4.37	1.495	1
4.4	1.495	1
4.43	1.487	1
4.47	1.487	1
4.5	1.487	1
4.53	1.478	1
4.57	1.478	1
4.6	1.47	1
4.63	1.47	1
4.67	1.462	1

FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
4.7	1.462	1
4.73	1.453	1
4.77	1.453	1
4.8	1.445	1
4.83	1.445	1
4.87	1.436	1
4.9	1.436	1
4.93	1.436	1
4.97	1.428	1
5	1.428	1
5.03	1.419	1
5.07	1.419	1
5.1	1.419	1
5.13	1.411	1
5.17	1.402	1
5.2	1.402	1
5.23	1.394	1
5.27	1.394	1
5.3	1.385	1
5.33	1.385	1
5.37	1.377	1
5.4	1.377	1
5.43	1.369	1
5.47	1.369	1
5.5	1.369	1
5.53	1.36	1
5.57	1.36	1
5.6	1.352	1
5.63	1.352	1
5.67	1.343	1
5.7	1.352	1
5.73	1.343	1
5.77	1.335	1
5.8	1.335	1
5.83	1.326	1
5.87	1.326	1
5.9	1.318	1
5.93	1.318	1
5.97	1.309	1
6	1.309	1
6.03	1.309	1
6.07	1.301	1
6.1	1.301	1
6.13	1.293	1
6.17	1.293	1
6.2	1.293	1
6.23	1.284	1

FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
6.27	1.284	1
6.3	1.276	1
6.33	1.276	1
6.37	1.267	1
6.4	1.267	1
6.43	1.267	1
6.47	1.259	1
6.5	1.25	1
6.53	1.25	1
6.57	1.25	1
6.6	1.242	1
6.63	1.242	1
6.67	1.242	1
6.7	1.233	1
6.73	1.233	1
6.77	1.233	1
6.8	1.225	1
6.83	1.216	1
6.87	1.225	1
6.9	1.216	1
6.93	1.216	1
6.97	1.208	1
7	1.208	1
7.03	1.208	1
7.07	1.208	1
7.1	1.2	1
7.13	1.191	1
7.17	1.191	1
7.2	1.191	1
7.23	1.183	1
7.27	1.183	1
7.3	1.174	1
7.33	1.174	1
7.37	1.174	1
7.4	1.166	1
7.43	1.166	1
7.47	1.166	1
7.5	1.157	1
7.53	1.157	1
7.57	1.149	1
7.6	1.157	1
7.63	1.149	1
7.67	1.149	1
7.7	1.149	1
7.73	1.14	1
7.77	1.132	1
7.8	1.132	1

FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
7.83	1.132	1
7.87	1.124	1
7.9	1.124	1
7.93	1.124	1
7.97	1.115	1
8	1.115	1
8.03	1.115	1
8.07	1.107	1
8.1	1.107	1
8.13	1.098	1
8.17	1.098	1
8.2	1.09	1
8.23	1.09	1
8.27	1.09	1
8.3	1.09	1
8.33	1.081	1
8.37	1.081	1
8.4	1.081	1
8.43	1.073	1
8.47	1.073	1
8.5	1.064	1
8.53	1.064	1
8.57	1.064	1
8.6	1.064	1
8.63	1.056	1
8.67	1.064	1
8.7	1.056	1
8.73	1.056	1
8.77	1.047	1
8.8	1.047	1
8.83	1.047	1
8.87	1.039	1
8.9	1.039	1
8.93	1.031	1
8.97	1.031	1
9	1.031	1
9.03	1.022	1
9.07	1.022	1
9.1	1.022	1
9.13	1.014	1
9.17	1.014	1
9.2	1.014	1
9.23	1.005	1
9.27	1.014	1
9.3	1.005	1
9.33	0.997	1
9.37	0.997	1

FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
9.4	0.997	1
9.43	0.997	1
9.47	0.988	1
9.5	0.997	1
9.53	0.988	1
9.57	0.988	1
9.6	0.98	1
9.63	0.98	1
9.67	0.98	1
9.7	0.971	1
9.73	0.971	1
9.77	0.963	1
9.8	0.963	1
9.83	0.963	1
9.87	0.963	1
9.9	0.955	1
9.93	0.955	1
9.97	0.955	1
10	0.955	1
10.03	0.955	1
10.07	0.946	1
10.1	0.946	1
10.13	0.938	1
10.17	0.946	1
10.2	0.938	1
10.23	0.938	1
10.27	0.938	1
10.3	0.929	1
10.33	0.929	1
10.37	0.921	1
10.4	0.921	1
10.43	0.921	1
10.47	0.921	1
10.5	0.921	1
10.53	0.912	1
10.57	0.912	1
10.6	0.912	1
10.63	0.904	1
10.67	0.912	1
10.7	0.904	1
10.73	0.904	1
10.77	0.904	1
10.8	0.895	1
10.83	0.895	1
10.87	0.887	1
10.9	0.887	1
10.93	0.887	1

FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
10.97	0.879	1
11	0.879	1
11.03	0.879	1
11.07	0.879	1
11.1	0.879	1
11.13	0.879	1
11.17	0.87	1
11.2	0.87	1
11.23	0.87	1
11.27	0.862	1
11.3	0.862	1
11.33	0.862	1
11.37	0.853	1
11.4	0.853	1
11.43	0.853	1
11.47	0.853	1
11.5	0.853	1
11.53	0.845	1
11.57	0.845	1
11.6	0.845	1
11.63	0.836	1
11.67	0.836	1
11.7	0.836	1
11.73	0.836	1
11.77	0.836	1
11.8	0.836	1
11.83	0.828	1
11.87	0.828	1
11.9	0.828	1
11.93	0.828	1
11.97	0.819	1
12	0.819	1
12.03	0.819	1
12.07	0.811	1
12.1	0.819	1
12.13	0.811	1
12.17	0.811	1
12.2	0.811	1
12.23	0.811	1
12.27	0.802	1
12.3	0.802	1
12.33	0.802	1
12.37	0.802	1
12.4	0.802	1
12.43	0.802	1
12.47	0.794	1
12.5	0.794	1

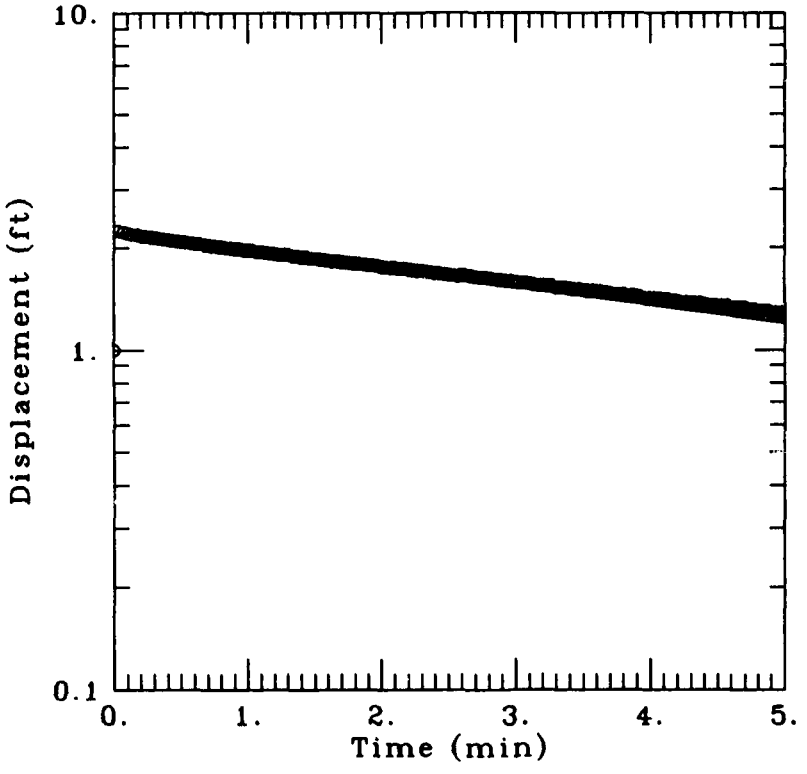
FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
12.53	0.794	1
12.57	0.786	1
12.6	0.786	1
12.63	0.786	1
12.67	0.786	1
12.7	0.777	1
12.73	0.777	1
12.77	0.777	1
12.8	0.777	1
12.83	0.777	1
12.87	0.769	1
12.9	0.769	1
12.93	0.769	1
12.97	0.769	1
13	0.769	1
13.03	0.76	1
13.07	0.76	1
13.1	0.76	1
13.13	0.76	1
13.17	0.752	1
13.2	0.76	1
13.23	0.752	1
13.27	0.752	1
13.3	0.752	1
13.33	0.743	1
13.37	0.743	1
13.4	0.743	1
13.43	0.743	1
13.47	0.743	1
13.5	0.735	1
13.53	0.735	1
13.57	0.735	1
13.6	0.735	1
13.63	0.735	1
13.67	0.726	1
13.7	0.726	1
13.73	0.726	1
13.77	0.718	1
13.8	0.726	1
13.83	0.718	1
13.87	0.718	1
13.9	0.718	1
13.93	0.718	1
13.97	0.718	1
14	0.71	1
14.03	0.718	1
14.07	0.71	1

FT-01, Well MW-227 Rising Head 1

Time	Head Change	Unit
14.1	0.71	1
14.13	0.71	1
14.17	0.71	1
14.2	0.71	1
14.23	0.71	1
14.27	0.701	1
14.3	0.701	1
14.33	0.701	1
14.37	0.693	1
14.4	0.693	1

FT-01, Well MW-227 (Rising Head Test 2)



DATA SET:

10/09/97

AQUIFER TYPE:
Unconfined

SOLUTION METHOD
Bouwer-Rice

ESTIMATED PARAMETERS
K = 9.5318E-05 ft/min
y0 = 2.227 ft

TEST DATA:
H0 = 1 ft
rc = 0.0835 ft
rw = 0.333 ft
L = 10 ft
D = 25 ft
H = 10 ft

FT-01, Well MW-227 Rising Head 2

Time	Head Change	Unit
0	2.2808	1
0.03	2.247	1
0.07	2.2301	1
0.1	2.2132	1
0.13	2.1964	1
0.17	2.1879	1
0.2	2.171	1
0.23	2.1626	1
0.27	2.1541	1
0.3	2.1457	1
0.33	2.1372	1
0.37	2.1203	1
0.4	2.1119	1
0.43	2.1034	1
0.47	2.095	1
0.5	2.0865	1
0.53	2.0781	1
0.57	2.0696	1
0.6	2.0612	1
0.63	2.0527	1
0.67	2.0443	1
0.7	2.0358	1
0.73	2.0274	1
0.77	2.0189	1
0.8	2.0105	1
0.83	2.002	1
0.87	1.9936	1
0.9	1.9851	1
0.93	1.9851	1
0.97	1.9682	1
1	1.9682	1
1.03	1.9598	1
1.07	1.9429	1
1.1	1.9429	1
1.13	1.9344	1
1.17	1.926	1
1.2	1.9175	1
1.23	1.9091	1
1.27	1.9091	1
1.3	1.9006	1
1.33	1.8922	1
1.37	1.8837	1
1.4	1.8753	1
1.43	1.8753	1
1.47	1.8584	1
1.5	1.8584	1
1.53	1.8499	1

FT-01, Well MW-227 Rising Head 2

Time	Head Change	Unit
1.57	1.8415	1
1.6	1.833	1
1.63	1.8246	1
1.67	1.8246	1
1.7	1.8161	1
1.73	1.8077	1
1.77	1.7992	1
1.8	1.7908	1
1.83	1.7908	1
1.87	1.7823	1
1.9	1.7739	1
1.93	1.7739	1
1.97	1.7654	1
2	1.757	1
2.03	1.7485	1
2.07	1.7401	1
2.1	1.7401	1
2.13	1.7316	1
2.17	1.7316	1
2.2	1.7232	1
2.23	1.7147	1
2.27	1.7063	1
2.3	1.7063	1
2.33	1.6978	1
2.37	1.6894	1
2.4	1.6809	1
2.43	1.6809	1
2.47	1.6725	1
2.5	1.664	1
2.53	1.656	1
2.57	1.648	1
2.6	1.648	1
2.63	1.648	1
2.67	1.639	1
2.7	1.631	1
2.73	1.622	1
2.77	1.622	1
2.8	1.614	1
2.83	1.605	1
2.87	1.597	1
2.9	1.597	1
2.93	1.588	1
2.97	1.588	1
3	1.58	1
3.03	1.572	1
3.07	1.572	1
3.1	1.563	1

FT-01, Well MW-227 Rising Head 2

Time	Head Change	Unit
3.13	1.555	1
3.17	1.546	1
3.2	1.546	1
3.23	1.538	1
3.27	1.538	1
3.3	1.521	1
3.33	1.521	1
3.37	1.521	1
3.4	1.512	1
3.43	1.504	1
3.47	1.504	1
3.5	1.496	1
3.53	1.487	1
3.57	1.487	1
3.6	1.479	1
3.63	1.479	1
3.67	1.47	1
3.7	1.462	1
3.73	1.453	1
3.77	1.453	1
3.8	1.453	1
3.83	1.436	1
3.87	1.445	1
3.9	1.436	1
3.93	1.428	1
3.97	1.419	1
4	1.419	1
4.03	1.419	1
4.07	1.411	1
4.1	1.403	1
4.13	1.403	1
4.17	1.394	1
4.2	1.386	1
4.23	1.377	1
4.27	1.377	1
4.3	1.369	1
4.33	1.369	1
4.37	1.369	1
4.4	1.36	1
4.43	1.352	1
4.47	1.352	1
4.5	1.343	1
4.53	1.343	1
4.57	1.343	1
4.6	1.327	1
4.63	1.327	1
4.67	1.327	1

FT-01, Well MW-227 Rising Head 2

Time	Head Change	Unit
4.7	1.327	1
4.73	1.31	1
4.77	1.31	1
4.8	1.301	1
4.83	1.301	1
4.87	1.301	1
4.9	1.284	1
4.93	1.284	1
4.97	1.284	1
5	1.276	1
5.03	1.276	1
5.07	1.267	1
5.1	1.267	1
5.13	1.259	1
5.17	1.259	1
5.2	1.25	1
5.23	1.25	1
5.27	1.242	1
5.3	1.234	1
5.33	1.234	1
5.37	1.234	1
5.4	1.225	1
5.43	1.217	1
5.47	1.217	1
5.5	1.217	1
5.53	1.208	1
5.57	1.208	1
5.6	1.2	1
5.63	1.2	1
5.67	1.191	1
5.7	1.191	1
5.73	1.183	1
5.77	1.183	1
5.8	1.174	1
5.83	1.174	1
5.87	1.166	1
5.9	1.166	1
5.93	1.158	1
5.97	1.158	1
6	1.158	1
6.03	1.149	1
6.07	1.149	1
6.1	1.141	1
6.13	1.132	1
6.17	1.132	1
6.2	1.132	1
6.23	1.124	1

FT-01, Well MW-227 Rising Head 2

Time	Head Change	Unit
6.27	1.124	1
6.3	1.124	1
6.33	1.115	1
6.37	1.115	1
6.4	1.107	1
6.43	1.107	1
6.47	1.098	1
6.5	1.098	1
6.53	1.09	1
6.57	1.09	1
6.6	1.09	1
6.63	1.081	1
6.67	1.081	1
6.7	1.081	1
6.73	1.073	1
6.77	1.073	1
6.8	1.065	1
6.83	1.056	1
6.87	1.065	1
6.9	1.056	1
6.93	1.056	1
6.97	1.048	1
7	1.048	1
7.03	1.039	1
7.07	1.039	1
7.1	1.031	1
7.13	1.031	1
7.17	1.031	1
7.2	1.022	1
7.23	1.022	1
7.27	1.014	1
7.3	1.014	1
7.33	1.005	1
7.37	1.014	1
7.4	1.005	1
7.43	1.005	1
7.47	0.997	1
7.5	0.997	1
7.53	0.997	1
7.57	0.989	1
7.6	0.989	1
7.63	0.98	1
7.67	0.98	1
7.7	0.98	1
7.73	0.972	1
7.77	0.972	1
7.8	0.972	1

FT-01, Well MW-227 Rising Head 2

Time	Head Change	Unit
7.83	0.972	1
7.87	0.963	1
7.9	0.963	1
7.93	0.963	1
7.97	0.955	1
8	0.955	1
8.03	0.946	1
8.07	0.946	1
8.1	0.938	1
8.13	0.938	1
8.17	0.938	1
8.2	0.929	1
8.23	0.929	1
8.27	0.929	1
8.3	0.921	1
8.33	0.921	1
8.37	0.921	1
8.4	0.913	1
8.43	0.913	1
8.47	0.913	1
8.5	0.904	1
8.53	0.904	1
8.57	0.904	1
8.6	0.896	1
8.63	0.904	1
8.67	0.896	1
8.7	0.896	1
8.73	0.887	1
8.77	0.887	1
8.8	0.879	1
8.83	0.879	1
8.87	0.879	1
8.9	0.87	1
8.93	0.87	1
8.97	0.87	1
9	0.862	1
9.03	0.862	1
9.07	0.862	1
9.1	0.853	1
9.13	0.853	1
9.17	0.853	1
9.2	0.845	1
9.23	0.845	1
9.27	0.845	1
9.3	0.845	1
9.33	0.836	1
9.37	0.836	1

FT-01, Well MW-227 Rising Head 2

Time	Head Change	Unit
9.4	0.828	1
9.43	0.828	1
9.47	0.828	1
9.5	0.828	1
9.53	0.828	1
9.57	0.82	1
9.6	0.82	1
9.63	0.811	1
9.67	0.82	1
9.7	0.811	1
9.73	0.811	1
9.77	0.803	1
9.8	0.811	1
9.83	0.803	1
9.87	0.794	1
9.9	0.794	1
9.93	0.794	1
9.97	0.794	1
10	0.786	1
10.03	0.786	1
10.07	0.777	1
10.1	0.777	1
10.13	0.786	1
10.17	0.777	1
10.2	0.769	1
10.23	0.769	1
10.27	0.769	1
10.3	0.769	1
10.33	0.769	1
10.37	0.76	1
10.4	0.76	1
10.43	0.752	1
10.47	0.752	1
10.5	0.752	1
10.53	0.744	1
10.57	0.752	1

APPENDIX B

SOIL AND GROUNDWATER ANALYTICAL DATA

APPENDIX B.1

NOVEMBER 1995 SOIL AND GROUNDWATER ANALYTICAL DATA

MANTECH ENVIRONMENTAL TECHNOLOGY

Ref: 95-DK40\vg

November 27, 1995

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Dr. Kampbell:

This report contains the results of my GC/MSD analysis of Fairchild AFB core extracts for quantitation of benzene, toluene, trichloroethene (TCE), tetrachloroethene (PCE), ethylbenzene (EB), p-Xylene, m-Xylene, o-Xylene, 1,3,5-trimethylbenzene (1,3,5-TMB), 1,2,4-trimethylbenzene (1,2,4-TMB) and 1,2,3-trimethylbenzene (1,2,3-TMB) (Service Request #SF-2-171).

The analytical method was a modification of RSKSOP-124. Cool on-column injection (0.5 µl) was used with electronic pressure control set for a constant flow of 0.9 ml/min. A 30m X 0.25mm Restek Stabilwax (Crossbonded Carbowax-PEG, 0.5µm film) capillary GC column with 9" X 0.53 mm ID uncoated capillary precolumn was used. The ions chosen were those listed in EPA method 524.2 Revision 3.0. Standards calibration ranged from 0.01 to 300 µg/ml. A complete report detailing the acquisition method and calibration curve has been recorded. The samples were extracted by Mark Blankenship on November 21, 1995, with GC/MSD data acquisition on November 23, 1995.

If I can be of further assistance, please feel free to contact me.

Sincerely,

David A. Kovacs

xc: R.L. Cosby
J.L. Seeley
G.B. Smith

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SR SF-2-171 Fairchild AFB Dr. Kampbell

GC/MSD ... core extracts

Units = mg/kg

Sample	Benzene	TCE	PCE	Toluene	EB	p-Xylene	m-Xylene	o-Xylene	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
FES-5B-1-4'	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FES-5B-2-4' (1)	5.68E-01	ND	ND	5.08E+00	1.20E+00	6.97E+00	2.21E+01	9.88E+00	9.94E+00	1.86E+01	7.96E+00
FES-5B-2-4' (2)	2.66E-01	ND	ND	3.44E+00	1.09E+00	4.87E+00	1.47E+01	6.75E+00	7.06E+00	1.38E+01	5.78E+00
FES-5B-2-10'	3.21E-01	ND	2.58E-02	1.49E+00	5.24E+00	8.81E+00	2.74E+01	2.22E+00	1.70E+01	3.56E+01	1.50E+01
FES-5B-3-4'	1.79E-01	ND	6.81E-02	1.04E+00	1.82E+00	8.55E+00	2.03E+01	9.84E+00	1.24E+01	2.67E+01	1.25E+01
FES-5B-3-8' (1)	3.26E-01	ND	7.31E-02	1.95E-01	1.92E-01	1.06E+01	3.27E+01	1.19E+01	1.75E+01	3.49E+01	1.62E+01
FES-5B-3-8' (2)	2.55E-01	ND	4.90E-02	1.71E-01	2.84E-01	9.88E+00	3.04E+01	1.12E+01	1.63E+01	3.39E+01	1.58E+01
FES-5B-4-4'	BLQ	ND	ND	ND	BLQ	4.15E-02	7.57E-02	7.74E-02	1.41E-01	1.89E-01	1.27E-01
FES-5B-4-8' (1) **	2.09E-01	ND	6.77E-02	1.45E+00	5.68E-02	1.36E+01	3.97E+01	1.98E+01	2.33E+01	4.85E+01	2.26E+01
** The sample vial was received at RSKERL with loose and collapsed cap septum.											
FES-5B-4-8' (2)	2.42E-01	ND	5.30E-02	2.53E+00	5.09E-02	3.46E+01	9.94E+01	4.99E+01	5.66E+01	1.20E+02	5.58E+01
FES-MP-25-6' (45) mv	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FES-MP-35-4' ES-5B-5-4 mv	BLQ	ND	2.13E-02	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Check Standards (ug/ml)											
50 QC	4.73E+01	4.89E+01	4.80E+01	4.72E+01	4.79E+01	4.75E+01	4.76E+01	4.65E+01	4.71E+01	4.65E+01	4.69E+01
50 QC	5.39E+01	5.51E+01	5.38E+01	5.43E+01	5.45E+01	5.34E+01	5.40E+01	5.43E+01	5.55E+01	5.60E+01	5.66E+01
100	9.87E+01	9.80E+01	9.92E+01	9.98E+01	1.02E+02	9.88E+01	9.77E+01	9.91E+01	9.86E+01	9.90E+01	9.95E+01
100	1.01E+02	1.00E+02	1.01E+02	1.03E+02	1.01E+02	1.03E+02	1.03E+02	1.03E+02	1.03E+02	1.05E+02	1.03E+02
10	1.03E+01	1.02E+01	1.03E+01	1.04E+01	1.03E+01	1.06E+01	1.02E+01	1.03E+01	1.02E+01	1.05E+01	1.03E+01
1	1.05E+00	1.04E+00	1.05E+00	1.06E+00	1.06E+00	1.11E+00	1.08E+00	1.07E+00	1.03E+00	1.08E+00	1.05E+00
1	9.54E-01	9.73E-01	9.82E-01	9.77E-01	1.08E+00	1.03E+00	9.75E-01	9.88E-01	9.73E-01	8.94E-01	9.58E-01
0.1	1.01E-01	1.02E-01	1.00E-01	9.27E-02	9.87E-02	1.02E-01	1.13E-01	9.91E-02	8.66E-02	8.61E-02	9.72E-02
0.01	9.82E-03	1.11E-02	1.08E-02	1.11E-02	1.35E-02	1.34E-02	1.93E-02	1.49E-02	1.11E-02	1.72E-02	1.13E-02
Method Blank	ND	ND	ND	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	ND

Analyst: D.A. Kovacs

BLQ < 0.05 ug/ml

Printed: 11/27/95

MANTECH

Ref: 96-JH20/vg
96-SH24/vg

March 13, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Find attached results for TOC on a set of 9 soils received from Fairchild AFB January 7, 1996 under Service Request #SF-2-171 mod. 1. TOC results were done as per RSKSOP-102 and RSKSOP-120.

True values are:

WP034 II true at 6.3 mg/L
Leco Std soil true at 1.00 ± 0.04 % OC

If you have any questions concerning this data, please feel free to contact us.

Sincerely,

Jeff Hickerson

Sharon Hightower

xc: R.L. Cosby
G.B. Smith

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SR# SF-2-171
MOD 1

ANALYSIS PERFORMED 12-7-95

SAMPLE	%OC FILTRATES	%OC SOLIDS	%TOC TOTAL	MEAN %TOC
ES-5B-1-4-1-1	0.142	0.171	0.313	0.269
ES-5B-1-4-1-2	0.136	0.129	0.265	
ES-5B-2-4-1-1	0.511	0.572	1.08	1.084
ES-5B-2-4-1-2	0.534	0.551	1.09	
ES-5B-2-10-1-1	0.066	0.095	0.161	0.158
ES-5B-2-10-1-2	0.046	0.109	0.155	
ES-5B-3-4-1-1	0.835	1.68	2.52	2.61
ES-5B-3-4-1-2	1.03	1.68	2.71	
ES-5B-3-8-1-1	0.769	0.755	1.524	1.64
ES-5B-3-8-1-2	0.870	0.893	1.763	
ES-5B-4-4-1-1	0.481	0.378	0.859	0.867
ES-5B-4-4-1-2	0.462	0.413	0.875	
ES-5B-4-8-1-1	0.488	0.358	0.846	0.81
ES-5B-4-8-1-2	0.445	0.329	0.774	
ESMP-25-6-1-1	0.000	0.032	0.032	0.025
ESMP-25-6-1-2	0.000	0.023	0.023	
ESMP-25-6-1-3	0.005	0.016	0.021	
ESMP-35-4-1-1	0.231	0.258	0.489	0.478
ESMP-35-4-1-2	0.208	0.278	0.486	
WPO34-II	6.2 mg/L			
	6.4 mg/L			
LECO		1.01		
		1.01		
		1.01		
		1.01		

Printed 11/17/95 SF-2-171 DP-PT/GC:PID-FID Analyses for Dr. Don Kampbell Units = ng/mL Analyst: L. Black

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carb
10 PPB	11.4	11.4	11.3	11.7	10.7	10.4	10.6	10.0	10.6	N/A
QC, OBSERVED, PPB	51.0	51.4	55.4	52.2	51.6	51.2	53.3	47.2	47.4	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A
FES-GP-1	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
FES-GP-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FES-GP2 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FES-GP-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FES-GP-4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-3	174	4.8	198	184	465	8.8	96.6	274	151	1700
FMW-4	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	BLQ
FMW-49	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2 PPB	1.8	2.1	1.8	1.8	2.0	1.9	2.1	1.9	1.8	N/A
FMW-52	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-53	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-59	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-61	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-61 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-100	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-151	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-153	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-152	251	12.9	321	364	893	27.8	158	437	217	2900
FMW-154	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
FMW-155	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-156	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
50 PPB	50.9	49.9	51.1	52.4	51.7	48.4	52.8	49.3	50.2	N/A
FMW-225	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
FMW-226	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-227	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
10 PPB	10.1	10.0	9.9	10.1	9.8	9.3	10.0	8.9	9.5	N/A

ND = None Detected; N/A = Not Analyzed; BLQ = Below Limit of Quantitation, 2 ppb

MANTECH ENVIRONMENTAL TECHNOLOGY

Ref: 95-LP172/vg
95-CH79/vg

November 21, 1995

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are the results of 24 Fairchild AFB samples submitted to ManTech as part of S.R. #SF-2-171. The samples were received on November 8 and 9, 1995 and analyzed November 9 and 16. The methods used for analysis were EPA Method 353.1, 350.1, and Waters capillary electrophoresis Method N-601. Quality assurance measures performed on this set of samples included spikes, duplicates, known AQC samples and blanks.

If you have any questions concerning these results please feel free to contact us.

Sincerely,

Lynda Pennington

Lynda Pennington

Cherri Heard

Cherri Heard

xc: R.L. Cosby
J.L. Seeley
G.B. Smith

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	mg/L Cl^-	mg/L $SO_4^=$	mg/L $NO_2+NO_3(N)$	mg/L $NH_3(N)$
FES-GP-1	1.96	6.53	1.17	0.19
FES-GP-2	2.01	7.02	1.51	<0.05
FES-GP-4	1.86	9.40	2.39	<0.05
FMW-3	2.32	0.84	<0.05	0.23
FMW-52	1.40	7.10	2.57	<.05
FMW-52 Field Dup	1.40	6.86	2.28	<.05
FMW-52 Field Dup Rep	1.37	6.85	----	----
FMW-53	94.0	6.37	1.75	<.05
FMW-61	1.47	8.93	<0.05	<.05
FMW-61 Dup	----	----	<0.05	<.05
FMW-151	1.75	7.28	<0.05	<.05
FMW-152	2.33	0.80	<0.05	2.24
FMW-154	2.28	17.1	1.39	<.05
FMW-1	3.23	9.34	0.26	<.05
FMW-2	1.86	5.29	0.60	<.05
FMW-4	1.93	7.82	1.77	<.05
FMW-4 Dup	1.91	7.86	----	----
FMW-49	13.6	1.77	0.10	0.27
FMW-50	4.03	13.1	1.03	<.05
FMW-59	5.34	6.94	1.41	<.05
FMW-590	----	----	1.43	<.05
FMW-100	2.79	5.08	0.13	<.05
FMW-155	2.04	6.11	0.07	<.05
FMW-155	2.20	6.73	0.30	<.05
FMW-156	2.15	21.6	0.10	<.05
FMW-156 Dup	2.09	21.7	----	----
FMW-225	2.76	6.60	<0.05	0.41
FMW-226	2.25	3.83	<0.05	0.33
FMW-227	1.91	3.43	<0.05	0.12
Blank	<.5	<.5	<.05	<.05
AQC	60.6	21.4	6.00	8.71
AQC T.V.	59.2	22.0	6.02	8.80
Spike Rec.	100%	101%	102%	98%

MANTECH ENVIRONMENTAL TECHNOLOGY

Ref: 95-JH77/vg

November 28, 1995

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Find attached results for methane, ethylene, and ethane on samples received November 8 and 9, 1995 under Service Request #SF-2-171. Samples were prepared and calculations done as per RSKSOP-175. Analyses were prepared as per RSKSOP-147.

If you have any questions concerning this data, please feel free to contact me.

Sincerely,

Jeff Hickerson

Jeff Hickerson

xc: R.L. Cosby
J.L. Seeley JH
G.B. Smith

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SR# SF-2-171

ANALYSIS PERFORMED 11-9-95

SAMPLE	METHANE	ETHYLENE	ETHANE
LAB BLANK	BLQ	ND	ND
FMW-1	0.003	ND	ND
FMW-2	BLQ	ND	ND
FMW-4	BLQ	ND	ND
FMW-49	0.120	ND	ND
" FIELD DUP	0.106	ND	ND
" LAB DUP	0.095	ND	ND

ANALYSIS PERFORMED 11-22-95

SAMPLE	METHANE	ETHYLENE	ETHANE
LAB BLANK	BLQ	ND	ND
BLANK LABEL	BLQ	ND	ND
FMW-3	15.04	0.017	ND
FMW-52	BLQ	ND	ND
FMW-53	BLQ	ND	ND
" FIELD DUP	BLQ	ND	ND
FES-GP-1	0.983	BLQ	ND
FES-GP-2	0.004	ND	ND
FES-GP-4	BLQ	ND	ND
FES-GP-5 - FES-GP-3	BLQ	ND	ND
FMW-50	0.001	ND	ND
" LAB DUP	0.001	ND	ND
FMW-59	BLQ	ND	ND
FMW-60 - FMW-61	0.001	ND	ND
FMW-100	0.028	ND	BLQ
FMW-151	0.000	ND	ND
FMW-152	19.06	BLQ	ND
" FIELD DUP	19.03	BLQ	ND
FMW-153	0.454	ND	ND
FMW-154	BLQ	ND	ND
FMW-155	0.046	ND	ND
FMW-156	0.004	ND	ND
FMW-225	0.181	ND	ND
FMW-226	1.45	ND	ND
FMW-227	4.19	ND	ND
" LAB DUP	4.04	ND	BLQ
10 PPM CH4	10.00	NA	NA
100 PPM CH4	100.05	NA	NA
1000 PPM CH4	1000.23	NA	NA
1% CH4	1.04	NA	NA
10% CH4	10.00	NA	NA
10 PPM C2H4	NA	10.17	NA
100 PPM C2H4	NA	99.98	NA
10 PPM C2H6	NA	NA	10.18
100 PPM C2H6	NA	NA	99.98

LIMITS OF QUANTITATION.

METHANE	ETHYLENE	ETHANE
0.001	0.003	0.002

SAMPLE UNITS ARE mg/L.
STANDARDS UNITS CORRESPOND
TO THE SAMPLE COLUMN.

BLQ DENOTES BELOW LIMIT OF QUANTITATION
ND DENOTES NONE DETECTED.
NA DENOTES NOT ANALYZED.

MANTECH

Ref: 95-DF70

Nov. 28, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

As requested in Service Request SF-2-171, GC/MS analysis for phenols and aliphatic/aromatic acids was done on triplicate water samples from two well sites, FMW-3 and FMW-52, at Fairchild AFB. One of the triplicate samples was preserved with H_2SO_4. A second was preserved with 10% Na_3PO_4 and the third was provided without preservation. Derivatization of the sample was done by Amy Zhao on Nov. 22, 1995. The extract was analyzed by GC/MS on Nov. 22 - 23, 1995. RSKERL SOP 177 was used for the extraction, derivatization and GC/MS analysis of the samples.

Table I provides the concentrations of the phenols and aliphatic/aromatic acids found in the Fairchild AFB samples. Please note that the calibration curve for benzoic acid could not be used due to high background levels of benzoic acid in the derivatization blank.

Comparison of the Na_3PO_4 and H_2SO_4 preserved samples with the unpreserved sample indicates that there is good agreement for the levels of trimethylacetic acid, 3,3-dimethylbutyric acid and 2-ethylhexanoic acid found in sample FMW-3. However, there is a hint of a problem indicated with the use of Na_3PO_4 as a preservative. The levels of phenol, o,m-ethylphenol, 2,4-, 3,5- and 2,3-dimethylphenol are lower in the Na_3PO_4 preserved sample than in the unpreserved sample. Within the next few weeks spiked water samples will be prepared and preserved with Na_3PO_4 and H_2SO_4. Comparisons with unpreserved samples will be made at several concentration levels to determine if phenol levels are effected by Na_3PO_4 preservation.

Six extracted ion chromatograms showing the 143 m/z ion are provided to show the presence of C_8 aliphatic acids in these samples. The levels of these acids are not dependent on whether the water sample is preserved or unpreserved. This also indicates

that the acids are not an artifact of preservation. For sample FMW-3 these acids are the largest peaks in the chromatogram.

If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D. Fine

xc: J. Seeley
G. Smith
R. Cosby
J. Wilson

Table I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids for Samples from Fairchild AFB (Service Request SF-21-172).

		Concentration ppb						
		FMW-3 Not Preserved	FMW-3 Na_3PO_4 Added	FMW-3 H_2SO_4 Added	FMW-62 Not Preserved	FMW-62 Na_3PO_4 Added	FMW-62 H_2SO_4 Added	Standard Blank
1	PROPANOIC ACID – PFB	13	31	10	14	24	11	8
2	2-METHYLPROPANOIC ACID – PFB	***	13	***	***	***	***	N.F.
3	TRIMETHYL ACETIC ACID – PFB	12	11	11	8	15	9	***
4	BUTYRIC ACID – PFB	***	8	***	***	***	***	***
5	2-METHYLBUTYRIC ACID – PFB	***	***	***	N.F.	***	N.F.	N.F.
6	3-METHYLBUTYRIC ACID – PFB	***	***	***	N.F.	***	N.F.	N.F.
7	3,3-DIMETHYLBUTYRIC ACID – PFB	26	23	23	7	8	7	N.F.
8	PENTANOIC ACID – PFB	***	***	***	***	***	***	***
9	2,3-DIMETHYLBUTYRIC ACID – PFB	***	***	***	N.F.	N.F.	N.F.	N.F.
10	2-ETHYLBUTYRIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
11	2-METHYLPENTANOIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
12	3-METHYLPENTANOIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
13	4-METHYLPENTANOIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
14	HEXANOIC ACID – PFB	5	7	***	5	***	5	***
15	2-METHYLHEXANOIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
16	PHENOL – PFB	15	***	***	32	***	***	***
17	CYCLOPENTANECARBOXYLIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
18	5-METHYLHEXANOIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
19	o-CRESOL – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
20	2-ETHYLHEXANOIC ACID – PFB	550	449	478	***	***	***	***
21	HEPTANOIC ACID – PFB	***	***	***	***	***	***	***
22	m-CRESOL – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
23	p-CRESOL – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
24	1-CYCLOPENTENE-1-CARBOXYLIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
25	o-ETHYLPHENOL – PFB	13	N.F.	***	***	N.F.	N.F.	N.F.
26	CYCLOPENTANEACETIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
27	2,6-DIMETHYLPHENOL – PFB	***	N.F.	***	***	N.F.	***	N.F.
28	2,5-DIMETHYLPHENOL – PFB	***	N.F.	N.F.	5	N.F.	N.F.	N.F.
29	CYCLOHEXANECARBOXYLIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
30	3-CYCLOHEXENE-1-CARBOXYLIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
31	2,4-DIMETHYLPHENOL – PFB	122	7	135	30	N.F.	9	N.F.
32	3,5-DIMETHYLPHENOL & M-ETHYLPHENOL – PFB	23	12	27	7	N.F.	***	N.F.
33	OCTANOIC ACID – PFB	***	***	***	***	***	***	***
34	2,3-DIMETHYLPHENOL – PFB	11	5	11	***	N.F.	***	N.F.
35	p-ETHYLPHENOL – PFB	N.F.	5	N.F.	5	N.F.	N.F.	N.F.
36	BENZOIC ACID – PFB	*	*	*	*	*	*	*
37	3,4-DIMETHYLPHENOL – PFB	***	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
38	m-METHYLBENZOIC ACID – PFB	***	N.F.	***	N.F.	N.F.	N.F.	N.F.
39	1-CYCLOHEXENE-1-CARBOXYLIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
40	CYCLOHEXANEACETIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
41	2-PHENYLPROPANOIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
42	o-METHYLBENZOIC ACID – PFB	***	***	***	N.F.	N.F.	N.F.	N.F.
43	PHENYLACETIC ACID – PFB	***	***	***	***	***	***	***
44	m-TOLYLACETIC ACID – PFB	6	5	6	9	8	9	N.F.
45	o-TOLYLACETIC ACID – PFB	***	***	***	***	***	***	N.F.
46	2,6-DIMETHYLBENZOIC ACID – PFB	***	***	***	***	***	***	N.F.
47	p-TOLYLACETIC ACID – PFB	6	***	***	6	6	9	N.F.
48	p-METHYLBENZOIC ACID – PFB	***	N.F.	***	***	N.F.	N.F.	N.F.
49	3-PHENYLPROPANOIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
50	2,5-DIMETHYLBENZOIC ACID – PFB	6	***	6	***	***	***	N.F.
51	DECANOIC ACID – PFB	***	***	***	***	***	***	N.F.
52	2,4-DIMETHYLBENZOIC ACID – PFB	5	***	5	***	***	***	N.F.
53	3,5-DIMETHYLBENZOIC ACID – PFB	***	***	***	***	N.F.	***	N.F.
54	2,3-DIMETHYLBENZOIC ACID – PFB	***	***	***	***	***	***	N.F.
55	4-ETHYLBENZOIC ACID – PFB	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.	N.F.
56	2,4,6-TRIMETHYLBENZOIC ACID – PFB	7	5	6	6	5	6	N.F.
57	3,4-DIMETHYLBENZOIC ACID – PFB	***	5	6	***	***	6	N.F.
58	2,4,5-TRIMETHYLBENZOIC ACID – PFB	5	***	***	***	***	***	N.F.

* Indicates that the calibration curve for benzoic acid is unusable due to benzoic acid contamination in derivatization blank.

*** Indicates concentration of extract was below lowest calibration standard (5 ppb).

N.F. Indicates not found.

MANTECH

Ref: 95/JAD61

November 30, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

As requested in Service Request # SF-2-171, headspace GC/MS analysis of 24 Fairchild AFB water samples for chlorinated volatiles was completed. The samples were received on November 9, 1995 and analyzed on November 22, 1995. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for the 9 compounds. The standard curves were prepared from 1.0 to 2000 ppb. The lower calibration limits were 1.0 ppb.

A quantitation report for the samples, lab duplicates, field duplicates, QC standards and lab blanks is presented in table 1-2.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel

xc: R.L. Cosby
G.B. Smith
D.D. Fine
J.L. Seeley JS
J.T. Wilson

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Table 1. Quantitation Report for S.R. # SF-2-171 from Fairchild AFB.

Concentration = ppb

Compound	FES-GP-1	FES-GP-2	FES-GP-3	FES-GP-4	FMW-1	FMW-2	FMW-3	FMW-3 Field Dup	FMW-4	FMW-49
VINYL CHLORIDE	2.4	ND	ND	ND	ND	ND	37.9	35.3	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	3.2	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	---	ND	ND	ND	---	7.1	1.2	1.0	---	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	---	---	1.0	ND	ND	---	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

	FMW-50	FMW-50 Lab Dup	FMW-52	FMW-53	FMW-59	FMW-61	FMW-100	FMW-151	FMW-152	FMW-152 Field Dup
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	2.2	ND	26.7	25.8
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	---	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	---	---	ND	ND	ND	ND	1.0	---	1.1	1.0
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	3.5	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	1.3	1.1	ND	---	ND	ND	---	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

	FMW-153	FMW-154	FMW-155	FMW-155 Lab Dup	FMW-156	FMW-225	FMW-225 Field Dup	FMW-226	FMW-227	QC1122A 20 ppb
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	4.0	21.1
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	21.6
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	19.5
C-1,2-DICHLOROETHENE	---	1.2	---	---	ND	---	---	1.0	---	19.1
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	21.4
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	21.7
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	21.2
TRICHLOROETHENE	---	---	---	---	ND	ND	ND	ND	ND	21.9
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	21.0

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate QC = Quality Control Std BL = Blank

MANTECH

Ref: 95-LP167/vg
95-MB15/vg

November 16, 1995

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are results of time-sensitive analyses done on groundwater samples taken at Fairchild AFB November 6, 7, and 8, 1995 as required by Service Request #SFTA-2-72. The analyses were done using meters, H_2S Hach Kit and Chemetrics Kits for phenol and manganese that were provided to us by Mike Cook and yourself.

Quality control consisted of checking meters daily before analyzing samples using provided check standards. If you have any questions concerning this data, please feel free to contact either of us.

Sincerely,

Lynda Pennington
Lynda Pennington

Mark Blankenship by LKP
Mark Blankenship

xc: R.L. Cosby
J.L. Seeley JS
G.B. Smith

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	pH	mV Redox	µS/cm Conductivity	°C Temperature	PPM H_2S	PPM Equivalent Phenol	PPM Manganese
FMW-4	7.23	-187	488	14.8	NA	<.1	0.6
FMW-156	8.48	-116	270	16.9	NA	NA	NA
FMW-155	7.21	+159	463	17.3	NA	<.1	<.1
FMW-49	7.25	+33	639	17.4	NA	<.1	2.0
FMW-59	7.50	+56	370	14.2	NA	<.1	<.1
FMW-225	7.30	-138	450	15.5	<.1	<.1	4.0
FMW-226	7.20	-108	471	16.6	<.1	<.1	9.0
FMW-50	7.25	+69	572	13.3	NA	<.1	<.1
FMW-227	7.21	-63	485	14.5	<.1	0.1	4.0
FMW-100	7.27	+177	540	13.0	NA	0.1	0.3
FMW-153	7.19	+171	446	12.3	NA	0.1	<.1
FMW-1	7.15	+159	477	13.8	NA	0.1	1.5
FMW-2	7.16	+156	403	14.6	NA	<.1	<.1
FES-GP-1	7.18	+135	366	12.8	NA	0.3	0.6
FMW-3	7.03	-148	474	16.9	<.1	NA	NA
FES-GP-3	7.51	-131	330	10.3	NA	NA	NA
FES-GP-2	7.29	+129	594	14.8	NA	0.1	0.3
FES-GP-4	7.26	+141	521	14.5	NA	0.1	0.3
FMW-154	8.81	+102	339	14.3	NA	<.1	<.1
FMW-151	7.27	+137	418	14.1	NA	0.1	0.3
FMW-53	7.55	+160	194	15.2	NA	0.1	<.1
FMW-152	6.95	129	673	15.2	<.1	*<.5	*7.5
FMW-61	7.83	-73	227	15.3	<.1	<.1	<.1
FMW-52	7.15	+62	252	16.3	NA	0.2	<.1
FMW-52 Dup	7.16	+95	257	17.4	NA	0.1	<.1

* Sample FMW-152 was diluted by 5 to dilute out interference.

Quality Control Data

Date	pH Buffer	pH Reading	1413 Cond.	"A" Redox	"B" Redox
Nov. 6, '95	4.00	4.11	1409	188.4	252.4
	7.00	7.02			
	10.00	9.87			
Nov. 7, '95	4.00	4.12	1409	186.5	250.9
	7.00	6.98			
	10.00	9.86			
Nov. 8, '95	4.00	4.11	1409	187.1	251.1
	7.00	7.01			
	10.00	9.86			

APPENDIX B.2

MAY 1996 GROUNDWATER ANALYTICAL DATA

Fairchild AFB

MANTECH

Ref: 96-SH55/vg

June 7, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Attached are TOC results for 14 Fairchild liquids submitted June 6, 1996 under Service Request #SF-2-208. Sample analysis was begun June 6, 1996 and completed June 6, 1996 using RSKSOP-102 and RSKSOP-120.

Blanks, duplicates, and AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,

Sharon Hightower

Sharon Hightower

xc: R.L. Cosby
G.B. Smith
J.L. Seeley JJ

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

KAMPBELL FAIRCHILD LIQUIDS SF-2-208

SAMPLE	MG/L TOC
FFT-GPC	48.9
FMW-2	1.27
FMW-3	5.71
FMW-4	9.90
FMW-5	5.98
FMW-6	14.4
FMW-7	2.67
FMW-8	6.50
FMW-8 DUP	6.74
FMW-9	2.16
FMW-10	2.53
FMW-11	2.92
FMW-12	3.55
FMW-1D	11.0
FMW-15	13.1
WPO34-I	19.22

WPO34-I std. t.v.=19.0

MANTECH

Ref: 96-JH59/vg

June 10, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Find attached results for methane and ethylene on samples received June 3, 1996 from Fairchild under Service Request #SF-2-208. Samples were prepared and calculations done as per RSKSOP-175. Analyses were performed as per RSKSOP-147.

If you have any questions concernin this data, please feel free to contact me.

Sincerely,

Jeff Hickerson

Jeff Hickerson

xc: R.L. Cosby
G.B. Smith
J.L. Seeley JS

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SR# SF-2-208
FAIRCHILD

ANALYSIS PERFORMED 6-5-96

SAMPLE	METHANE	ETHYLENE
LAB BLANK	BLQ	ND
FFT-GPC	15.87	ND
FMW-1D	0.011	BLQ
FMW-1S	0.013	BLQ
FMW-2	BLQ	ND
" LAB DUP	BLQ	ND
FMW-3	0.125	ND
FMW-4	0.001	ND
FMW-5	0.060	ND
FMW-6	1.87	ND
FMW-7	0.010	ND
" FIELD DUP	0.010	ND
FMW-8	0.001	ND
FMW-9	BLQ	ND
FMW-10	BLQ	ND
FMW-11	BLQ	ND
FMW-12	BLQ	ND
" LAB DUP	BLQ	ND
10 PPM CH4	10.00	NA
100 PPM C2H4	100.05	NA
1000 PPM CH4	1000.14	NA
1% CH4	1.00	NA
10% CH4	9.44	NA
20% CH4	20.26	NA
10 PPM C2H4	NA	10.14
100 PPM C2H4	NA	99.99

LIMITS OF QUANTITATION.

METHANE	ETHYLENE
0.001	0.003

SAMPLE UNITS ARE mg/L.
STANDARDS UNITS CORRESPOND
TO THE SAMPLE COLUMN.

BLQ DENOTES BELOW LIMIT OF QUANTITATION.
ND DENOTES NONE DETECTED.
NA DENOTES NOT ANALYZED.

FAIRCHILD AIR FORCE BASE
BUILDING 1212 SITE

Sample	TOC ft.	D.O. mg/L	Redox mV	pH	Sulfide mg/L	Ferrous Iron mg/L	Alk. mg$CaCO_3$/L	Well
5-29-96								
FMW-9	6.5	7.2	+120	7.06	<.1	<.1	640	2" clear
FMW-10	6.1	3.7	+119	6.94	<.1	<.1	580	2" clear
FMW-11	5.6	1.3	+116	6.77	<.1	<.1	620	2" clear
FMW-7	7.20	7.5	+110	6.78	<.1	<.1	580	2" clear
FMW-8	12.4	7.3	+74	7.16	ND	ND	ND	2" muddy
FMW-4	8.87	8.0	+94	6.73	<.1	<.1	620	2" clear
FMW-12	10.4	8.7	+87	7.02	<.1	<.1	340	2" clear
FMW-6	7.34	1.1	+5.0	6.67	<.1	3.2	1160	2"turbid
FMW-5	6.64	0.8	-121	6.40	0.2	0.9	440	2" clear
FMW-15	6.7	5.4	+30	6.87	<.1	<.1	920	2" cle
FMW-3	ND	0.7	-3.9	6.58	0.1	3.0	540	2"turbid
5-30-96								
FMW-1D	ND	4.2	+149	6.85	<.1	<.1	560	2" clear
FMW-2	ND	8.9	+91	7.32	<.1	<.1	440	2" clear
FMW-GP1	ND	8.3	ND	9.1	ND	ND	ND	hole muddy
FMW-GP2	ND	6.9	ND	7.6	ND	ND	ND	hole muddy BTEXXXBTM only
FFT-GPC	ND	0.5	-97	7.1	0.2	20.5	1260	GP-turbid

MANTECH ENVIRONMENTAL TECHNOLOGY

Ref: 96\LB45

June 20, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Please find attached the analytical results for Service Request SF-2-208 requesting the analysis of Fairchild AFB groundwater samples to be analyzed by purge-and-trap/GC-FID:PID for Benzene, Toluene, Ethylbenzene, p-, m-, & o-Xylene, 1,3,5-, 1,2,4-, & 1,2,3-Trimethylbenzene, and Total Fuel Carbon. We obtained the 17 groundwater samples, all but one in duplicate, in capped, 40 mL VOA autosampler vials on June 6, 1996, and they were analyzed on June 6, 1996. The samples were acquired and processed using the Millennium data system. A 5 place (1-1000 ppb) external standard curve was used to quantitate sample concentration for the compounds of interest.

RSKSOP-133, "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" was used for these analyses. Autosampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,

Lisa R. Black

Lisa R. Black

xc: R.L. Cosby
G.B. Smith
J.T. Wilson
J.L. Seeley JS

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
1 PPB	1.0	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	N/A
QC, OBSERVED, PPB	49.6	48.3	54.1	49.0	50.2	50.1	51.4	52.8	54.2	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A
FFT-GPC	229	273	616	968	2823	312	262	799	434	8298
FMW-GP1	BLQ	BLQ	ND	ND	BLQ	ND	ND	ND	ND	BLQ
FMW-GP2	BLQ	BLQ	ND	ND	BLQ	BLQ	ND	ND	ND	BLQ
FMW-Tank	*1.7	BLQ	ND	ND	ND	34.1	BLQ	ND	5.1	161
FMW-Tank Duplicate	*1.7	BLQ	ND	ND	BLQ	35.5	BLQ	ND	5.6	160
FMW-1D	109	371	415	1236	2529	1629	366	1480	433	10500
FMW-1S	291	673	892	2437	4909	3916	504	1953	697	16300
FMW-2	ND	ND	ND	BLQ	BLQ	BLQ	ND	BLQ	ND	BLQ
FMW-3	190	447	556	750	679	797	267	774	236	7097
FMW-4	BLQ	BLQ	1.1	1.4	2.4	1.4	BLQ	1.9	1.2	61.0
FMW-5	6.6	141	523	726	706	426	336	1010	236	9530
100 PPB	109	106	108	106	106	107	109	111	111	N/A
FMW-6	149	15.7	157	194	91.7	265	77.9	263	112	2130
FMW-7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-11 Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FMW-12	25.3	BLQ	BLQ	BLQ	ND	2.3	4.9	ND	4.3	93.2
QC, OBSERVED, PPB	50.7	48.3	53.5	23.8	49.0	50.0	50.3	51.4	52.7	N/A
QC, TRUE VALUE, PPB	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	N/A

*FID value used due to peak interference on PID

ND = None Detected; N/A = Not Analyzed; BLQ = Below Limit of Quantitation, 1 ppb

MANTECH

Ref: 96-TH34/vg
96-LP68/vg
96-JD25/vg
June 11, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

T' S.A. Vandegrift SV

L Don:

Attached are the results of 14 Fairchild AFB samples submitted to MERSC as part of Service Request #SF-2-208. The samples were received June 4, 1996 and analyzed June 5, 1996. The methods used for analysis were EPA Methods 353.1 for NO_2 and NO_3, 120.1 for Conductivity and Waters capillary electrophoresis Method N-601 for Cl and SO_4. Quality assurance measures performed on this set of samples included spikes, duplicates, known AQC samples and blanks.

If you have any questions concerning these results, please feel free to contact us.

Sincerely,

Tim Hensley by LKP
Tim Hensley

Lynda Pennington
Lynda Pennington

Justin Daniel
Justin Daniel by LKP

xc: R.L. Cosby
G.B. Smith
J.L. Seeley

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	mg/l $NO^-_2+NO^-_3$ (N)	mg/l Cl^-	mg/l SO_4^{-2}	$\mu S/Cm^3$ Cond.
FFT-GPC	<.05	3.25	<.5	542
FMW-1D	.08	5.91	6.87	340
FMW-1S	<.05	8.85	6.86	524
FMW-1S Dup	<.05	----	----	----
FMW-2	8.42	103	24.4	668
FMW-3	.27	53.9	8.02	553
FMW-4	.23	7.82	18.1	406
FMW-5	<.05	4.21	3.63	269
FMW-5 Dup	----	4.16	3.60	----
FMW-6	.08	16.0	18.4	621
FMW-6 Dup	----	----	----	620
FMW-7	.26	6.49	13.6	380
FMW-7 Dup	.27	----	----	----
FMW-8	1.72	7.85	59.8	396
FMW-9	2.11	8.02	25.1	424
FMW-10	1.35	6.87	30.7	383
FMW-11	.92	6.32	5.37	392
FMW-12	.62	10.4	21.3	266
Blank	<.05	<.5	<.5	1
AQC	.38	56.3	52.2	
AQC T.V.	.39	56.0	52.0	
Spike Rec.	99%	101%	103%	

MANTECH

Ref: NV120/vg

June 10, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: J.L. Seeley

Dear Don:

Attached is the metal analysis report (4489.LST) for 4 samples (Fairchild AFB) submitted to MERSC as part of Service Request #56 under EPA Contract #68-C3-0322. The samples were received on June 3, 1996 and analyzed June 3 and 4, 1996. The samples did not received any further treatment and they were analyzed using the ICAP system. GF-AAS was used for lead determinations and results are in report PB60603.Lis;2. SOP for the ICP, GF-AAS and sample calculations were according to the procedure and instructions provided by Mr. Don Clark.

If you have any questions, please feel free to contact me.

Sincerely,

Nohora Vela

Nohora Vela

xc: R.L. Cosby
R. Puls

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

THIS REPORT (USER$DISK:[CLARK.ICAP]LIST.LST;4469) IS GENERATED FROM USER$DISK:[CLARK.ICAP]OUTPUT.DAT;3041

PROJECT: AQ FILTERED SAMPLES. FAIRCHILD AFB.
KAMPBELL
SR56

CONCENTRATION IN: MG/L

TAG NO.	14234		14235		14236		14237		
STATION	FMW-1S		FMW-1D		FMW-4		FFT-GPC		
TIME	09:59		10:02		10:04		10:10		
DATE	04-JUN-96		04-JUN-96		04-JUN-96		04-JUN-96		
PR DIL	1.0000		1.0000		1.0000		1.0000		
DIL	1.0000		1.0000		1.0000		1.0000		
ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	13.1	1.3	13.5	1.3	30.5	3.0	17.3	1.7	0.0703
K	6.55	0.66	4.21	0.44	7.75	0.80	9.38	0.92	0.2983
Ca	71.6	7.1	42.1	4.2	39.5	3.9	66.3	6.6	0.0000
Mg	20.0	2.0	11.8	1.1	9.55	0.95	23.2	2.3	0.0241
Fe	<0.0036	0.0036	0.099	0.010	0.0222	0.0035	26.3	2.6	0.0035
Mn	2.73	0.27	1.32	0.13	0.259	0.025	3.92	0.39	0.0007
Co	0.0074	0.0036	0.0053	0.0036	0.0078	0.0036	0.0091	0.0036	0.0036
Mo	<0.020	0.020	<0.020	0.020	<0.020	0.020	<0.020	0.020	0.0202
Al	<0.019	0.019	<0.019	0.019	0.063	0.019	0.045	0.019	0.0191
As	<0.010	0.010	<0.010	0.010	0.0203	0.0099	0.058	0.012	0.0099
Se	<0.016	0.016	<0.016	0.016	<0.016	0.016	<0.028	0.028	0.0160
Cd	<0.0021	0.0021	<0.0021	0.0021	<0.0021	0.0021	0.0032	0.0021	0.0021
Be	<0.0015	0.0015	<0.0014	0.0014	<0.0014	0.0014	<0.0015	0.0015	0.0014
Cu	0.0144	0.0048	0.0146	0.0047	0.0262	0.0047	0.0550	0.0049	0.0047
Cr	<0.001	0.0011	<0.0011	0.0011	<0.0011	0.0011	<0.0011	0.0011	0.0011
Ni	0.011	0.0031	0.0053	0.0031	0.0046	0.0031	0.0116	0.0031	0.0031
Zn	0.000	0.0006	<0.0006	0.0006	0.0016	0.0006	0.0123	0.0018	0.0006
Ag	<0.0071	0.0071	<0.0071	0.0071	0.0131	0.0071	0.0110	0.0071	0.0071
Tl	<0.0097	0.0097	<0.0096	0.0096	<0.0096	0.0096	0.0001	0.0098	0.0096
Pb	<0.0082	0.0082	<0.0082	0.0082	<0.0082	0.0082	0.0008	0.0082	0.0082
Sr	0.497	0.049	0.229	0.023	0.319	0.032	0.492	0.049	0.0002
V	<0.010	0.010	<0.010	0.010	0.014	0.010	0.001	0.010	0.0103
Ba	0.278	0.028	0.106	0.010	0.133	0.013	0.203	0.020	0.0005
B	0.0300	0.0030	0.0024	0.0016	0.0106	0.0016	0.0144	0.0020	0.0015
Ti	<0.0019	0.0019	<0.0019	0.0019	<0.0019	0.0019	<0.0019	0.0019	0.0019

< VALUE=LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS

EPA/RSKERL/ADA, OK

MANTECH

Ref: 96-DF37

June 18, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

As requested in Service Request SF-2-208, GC/MS analysis for base/neutral extractable semi-volatile compounds was done on one water sample from the Fairchild AFB labeled FMW-1D. The sample was received on June 3, 1996. Extraction of the samples was done by Mark Blankenship on June 4, 1996. The extract was analyzed by GC/MS on June 14, 1996. EPA method 8270A with the modifications listed below was used for this analysis.

After the pH of one liter of each water sample was adjusted to slightly above 11.0 with 10N NaOH, it was extracted three times with 60 ml aliquots of methylene chloride. After the methylene chloride fraction was passed through a Na_2SO_4 column, it was concentrated using the Savant Concentrator to a final volume of 1.0 ml.

For qualitative analysis, the Hewlett Packard 7673 auto-injector delivered 1.0 μl of the methylene chloride extract of sample FTA-2-95 with splitless injection to a 60 meter, 0.25 mm DB5-MS capillary column with 0.25 μm film thickness. The column was temperature programmed from 40°C to 100°C at 30°C/min and then to 300°C at 6°C/min. The Finnigan 4615 GC/MS was scanned from 39 to 650 m/z in 0.5 sec.

Attached please find chromatograms of the base/neutral extract of the Fairchild sample. The extract contained high levels of the aromatic compounds ranging from xylenes to methyl

ManTech Environmental Research Services Corporation
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Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

naphthalenes. Three dimethylphenols and two benzenemethanol compounds were also found in the extract.

If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D. Fine

Dennis D. Fine

xc: J. Seeley
G. Smith
R. Cosby
D. Fine

Table 1. Quantitation Report for S.R. # SF-2-208 from Fairchild.

Concentration = ppb

Compound	FT-GPC	FT-GPC Lab Dup	FT-GPC Field Dup	QC0612D 200 ppb	QC0612E 20 ppb	BL0612B
VINYL CHLORIDE	11.9	11.3	12.2	183	18.7	ND
1,1-DICHLOROETHENE	---	---	---	199	20.4	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	213	22.1	ND
1,1-DICHLOROETHANE	ND	ND	ND	200	19.6	ND
C-1,2-DICHLOROETHENE	124	127	132	200	20.0	ND
CHLOROFORM	ND	ND	---	199	20.4	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	181	19.1	ND
CARBON TETRACHLORIDE	ND	ND	ND	173	18.9	ND
1,2-DICHLOROETHANE	ND	ND	ND	200	17.3	ND
TRICHLOROETHENE	63.4	65.3	64.6	170	17.5	ND
TETRACHLOROETHENE	ND	ND	ND	170	18.2	ND
CHLOROBENZENE	ND	ND	ND	169	19.5	ND

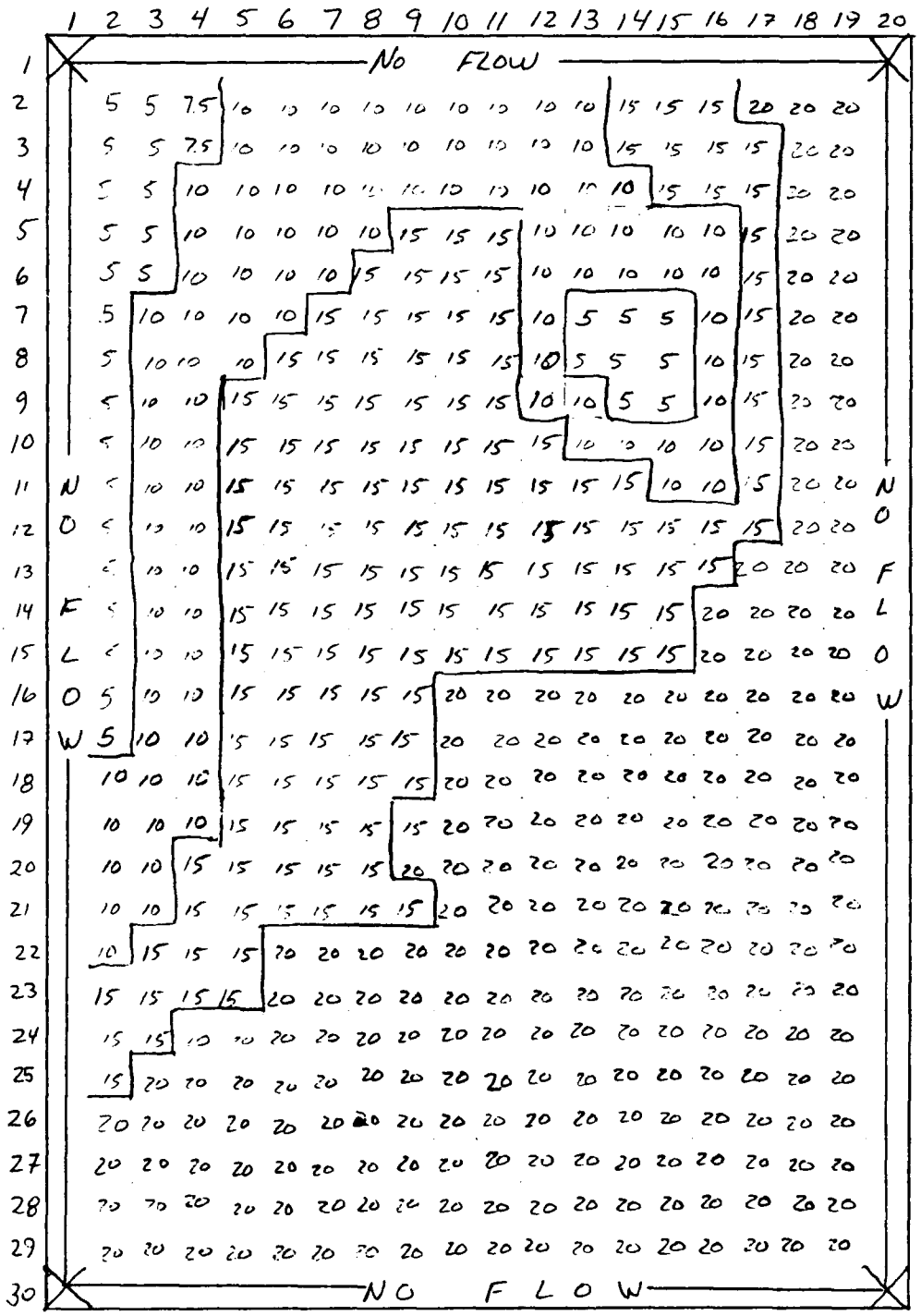
ND = None Detected QC = Quality Control Std. BL = Blank --- = Below Calibration Limit(1.0 ppb)

PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE - FAIRCHILD - FT-1 Job No. 722450.18 Sheet 1 of 1

Subject AQUIFER THICKNESS IN FEET By Date

Checked Rev.



APPENDIX C

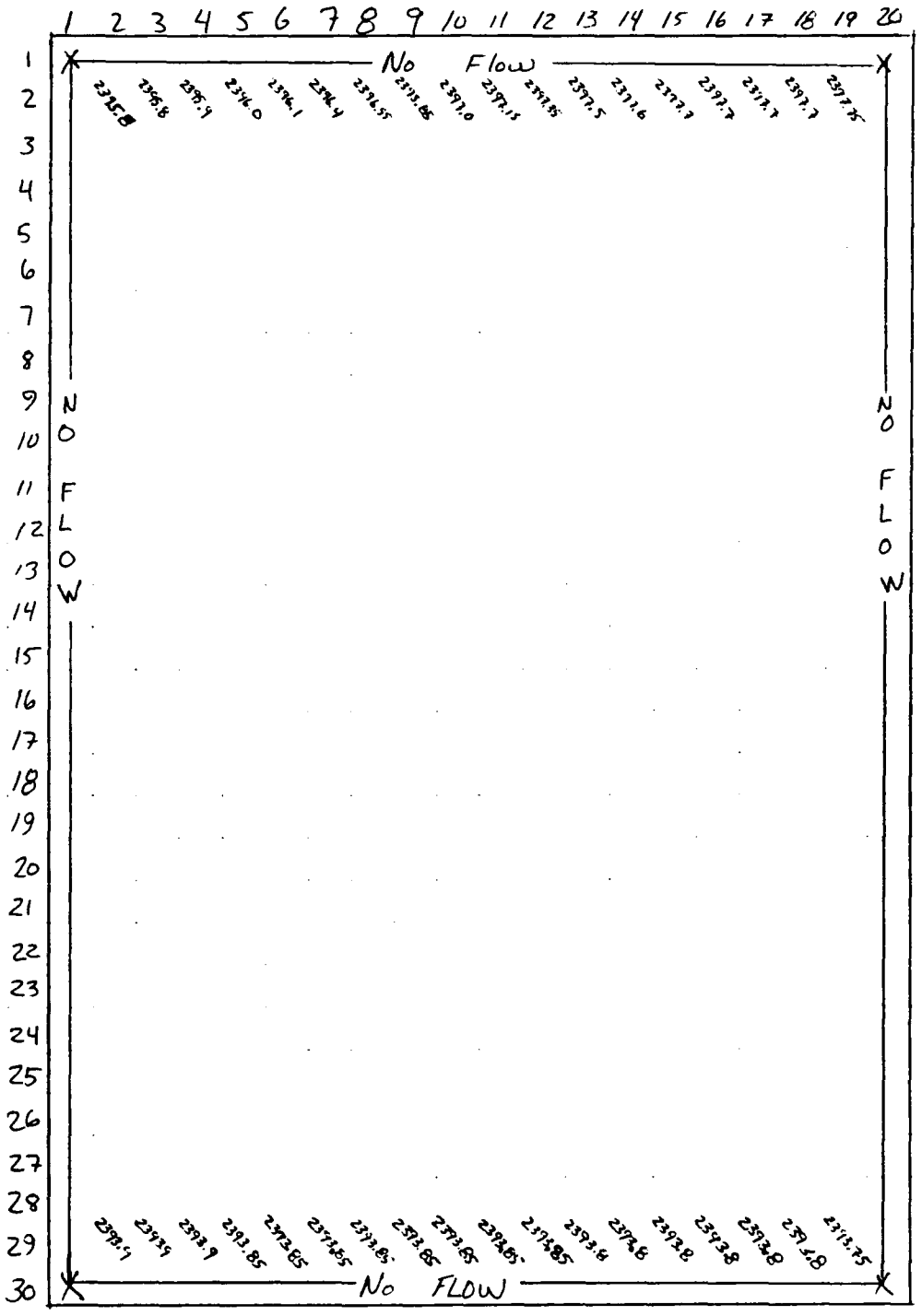
MODEL CALCULATIONS AND INPUT

PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE - FAIRCHILD AFB - FT-1 Job No. 722450.18 Sheet 1 of 1

Subject Constant Head MAP By Date

ELEVATIONS IN FEET MSL Checked Rev.

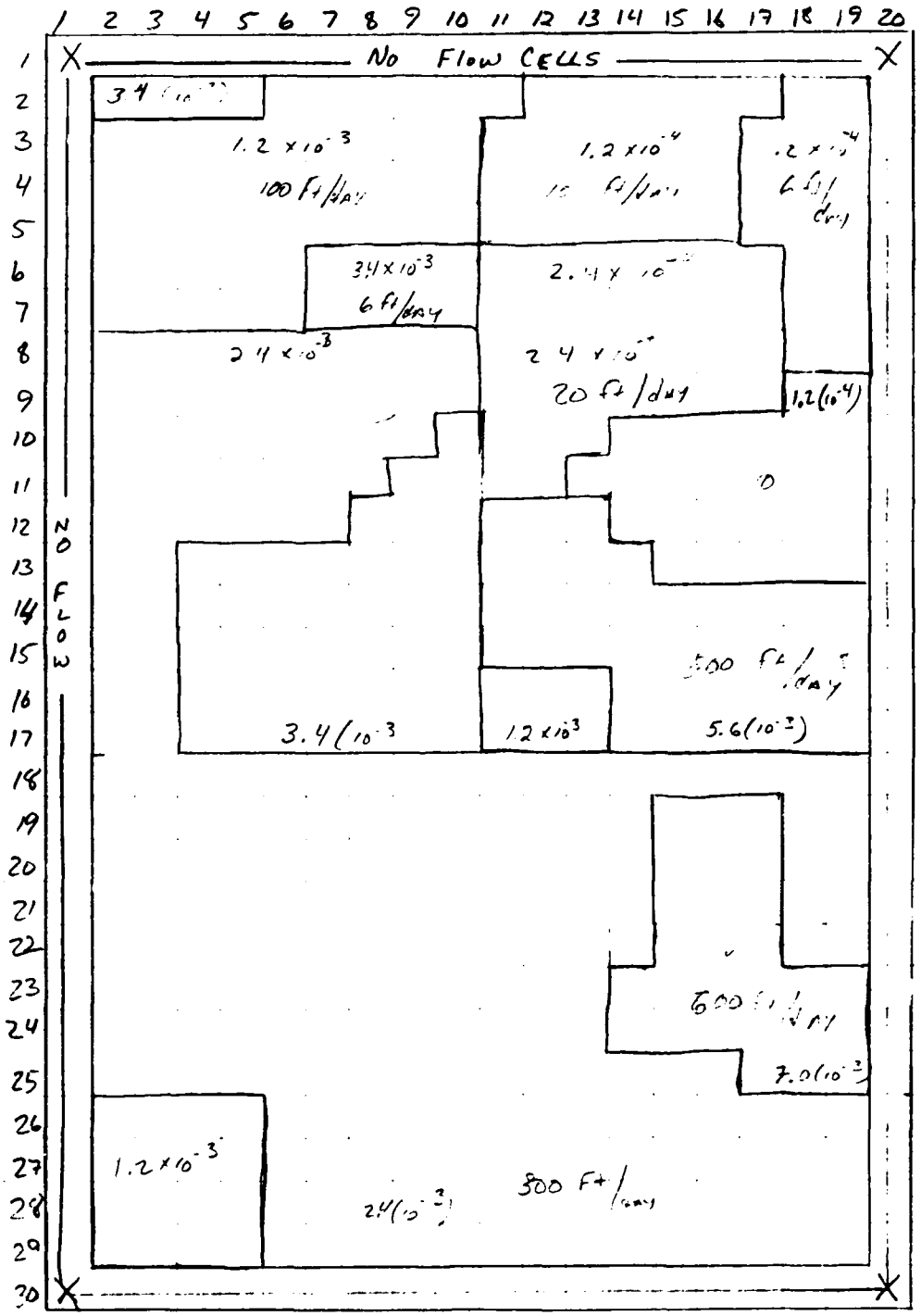


PARSONS ENGINEERING SCIENCE, INC.

Client AFCEE - FAIRCHILD AFB | Job No. | Sheet ___ of ___

Subject Transmissivity Grid | By | Date

| Checked | Rev. |



PESI-COR-8 (12/94)

MEAN ERROR, MEAN AVERAGE ERROR, AND ROOT-MEAN-SQUARE ERROR FOR THE CALIBRATED FLOW MODEL

FT-01

REMEDIATION BY NATURAL ATTENUATION TS
FAIRCHILD AIR FORCE BASE, WASHINGTON

Location	Actual Water Level (h_m)[a]	Calibrated Water Level (h_s)[a]	h_m-h_s	abs(h_m-h_s)	(h_m-h_s)^2
MW-1	2395.6	2395.8	0.19	0.19	0.04
MW-2					
MW-3	2395.5	2395.5	0.01	0.01	0.00
MW-4	2395.7	2396.0	0.27	0.27	0.07
MW-49	2394.4	2394.5	0.13	0.13	0.02
MW-50	2394.7	2394.5	-0.23	0.23	0.05
MW-148	2396.9	2397.0	0.06	0.06	0.00
MW-152	2395.2	2395.1	-0.09	0.09	0.01
MW-153	2395.0	2394.9	-0.07	0.07	0.00
MW-155	2395.2	2395.2	-0.04	0.04	0.00
MW-225	2394.6	2394.5	-0.11	0.11	0.01
MW-226	2394.8	2394.5	-0.28	0.28	0.08
MW-227	2395.0	2394.8	-0.14	0.14	0.02
Total:	28742.6	28742.3	-0.30	1.62	0.31
			ME[b] =	-0.02	
			MAE[c] =	0.14	
			RMS[d] =	0.16	4.0%

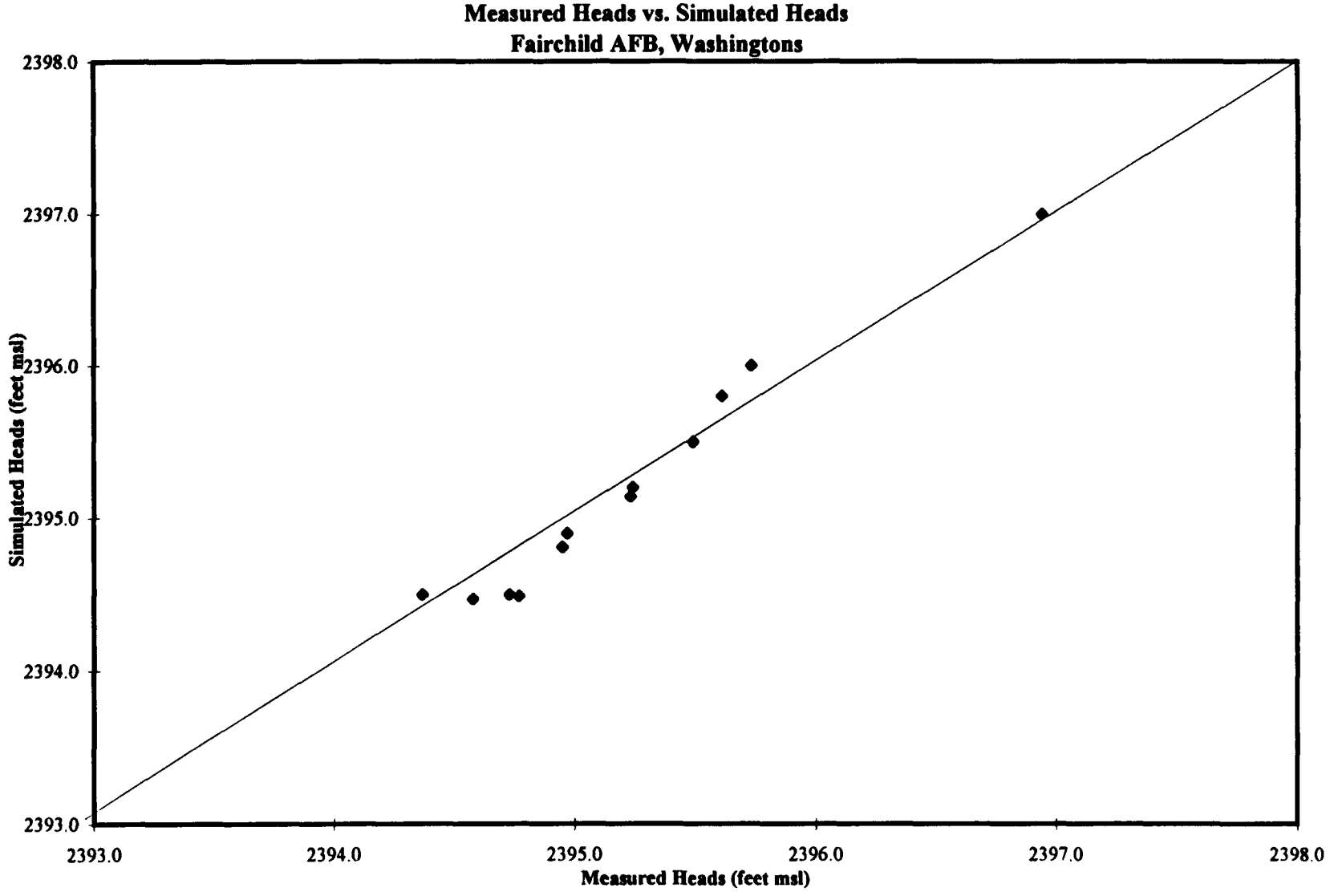
RMS ERROR PERCENT = $\frac{\text{RMS}}{\text{TOTAL Head Change}} \times 100$

[a] Water levels are in feet mean-sea-level.

[b] ME = Mean Error = $1/n \times (h_m-h_s)$.

[c] MAE = Mean Average Error = $1/n \times |(h_m-h_s)|$.

[d] RMS = Root-Mean-Square (RMS) Error = $(1/n \times (h_m-h_s)^2)^{0.5}$.



L:\45 model\WATSTAT.XLS

APPENDIX D

BIOPLUME II MODEL RESULTS